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BOSTON SOCIETY OF CIVIL ENGINEERS
FOUNDED 1848

PROCEEDINGS

PAPERS IN THIS NUMBER.

"Water-Power Development in New England." By H. K. Barrows.

"The St. Lawrence River Project." By Henry I. Harri-
man.

Memoir of deceased member.

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MINUTES OF MEETINGS.

BOSTON, December 17, 1920. — A regular meeting of the Boston Society of Civil Engineers was held this evening at Chipman Hall, Tremont Temple, and was called to order at 7.55 o'clock by the President, Frank A. Barbour.

The record of the last meeting was read and approved. The Secretary reported, for the Board of Government, the election of the following to membership in the grades named:

As members — Henry C. Archibald, William A. Brown, M. Warren Cowles, Silas Stanley Kent.

As a junior — Walter C. Richards.

The President announced the death of the following members of the Society: George S. Rice, who died December 7, 1920, and Edward A. Freeman, who died December 13, 1920.

By vote the President was requested to appoint committees to prepare memoirs, and the following appointments have been made: on memoir of Mr. Rice, Messrs. Desmond FitzGerald, Alfred D. Flinn, and E. W. Howe; and on memoir of Mr. Freeman, Prof. C. M. Spofford.

Mr. R. A. Hale, for himself and Mr. James R. Baldwin, the committee appointed to prepare a memoir of Loammi F. Baldwin, submitted their report, which was accepted and ordered printed in the JOURNAL of the Society.

Mr. E. W. Howe presented the following resolutions concerning a proposed amendment of the Federal Water Power Act, and moved their adoption, which was seconded by Mr. Desmond FitzGerald:

"Whereas, the Federal Water Power Act passed by the 66th Congress authorizes the Water Power Commission to issue licenses for 'constructing, operating and maintaining dams, water conduits, reservoirs, power houses, transmission lines or other project works' in the National Parks and Monuments on exactly the same basis as in the National Forests and other public lands, and

Whereas, irrigation interests are seeking rights for storage reservoirs in the National Parks and are strongly urging the passage of the precedent-making Falls River Basin Bill, otherwise known as the Smith Bill (H. R. 12416), which has passed the Senate and is pending before the House of Representatives with a favorable report, and which grants easements for 'irrigation plants, dams, reservoirs, canals, ditches, pipes and pipe lines' in Yellowstone National Park; now, therefore,

Be it resolved, that the Boston Society of Civil Engineers endorses the attempt to secure an amendment of the Act creating the Federal Power Commission which shall exempt the National Parks and Monuments from its provisions; and also

Be it resolved, that the Society specifically opposes the Falls River Basin Bill (H. R. 12466), believing it to be establishing a dangerous precedent and doing irreparable injury to a large section of one of the most important of our National Parks; and, furthermore,

Be it resolved, that the Board of Government of the Society be authorized and directed to coöperate with other organizations working for the protection of the National Parks and Monuments."

After a short discussion by Messrs. Howe, FitzGerald, W. H. Sawyer, S. H. Thorndike, J. E. L. Monaghan, and the

defeat of a motion to lay on the table until further information could be obtained, the resolutions were adopted. The President announced that the resolutions would now be sent out to a letter-ballot, as required by the Constitution of the Society.

The President stated that a communication had been received from the Joint Conference Committee inviting the Society to become a member of the Federated American Engineering Societies, and that it had been referred to a committee to consider the advisability of joining. The committee submitted its report to-day, but the question is so important that he felt that more time should be given to its consideration than is possible at this meeting; he therefore suggested that a special adjourned meeting be held for the purpose. It was accordingly voted that when the meeting adjourns it be to Wednesday evening, December 29, 1920.

At 8.15 o'clock the literary exercises of the evening were taken up. The President explained that this was the first of a series of three joint meetings held by the Boston Section of the American Society of Mechanical Engineers, the Boston Section of the American Institute of Electrical Engineers and the Boston Society of Civil Engineers. At these meetings hydroelectric development and transmission will be the subjects for discussion.

This, the first meeting of the series, he stated, is held under the auspices of this Society, and he introduced the first speaker of the evening, Prof. Harold K. Barrows, who read a paper entitled "Water-Power Development in New England." The paper was illustrated by a large number of lantern-slide diagrams.

The second speaker was Mr. Henry I. Harriman, president of the New England Power Company, who spoke of the so-called St. Lawrence Project.

At 10.15 the meeting was adjourned. The attendance of members of the three organizations and their guests was fully five hundred.

S. E. TINKHAM, *Secretary*.

BOSTON, December 29, 1920. — The adjourned meeting of the Society was called to order in the Society rooms by the President, Mr. Frank A. Barbour, at 7.55 o'clock P.M.

There were 35 members present. The President said that this adjournment of the regular December meeting had been made to give sufficient time for the discussion of the important question of the Society affiliating with the Federated American Engineering Societies.

He stated that a communication had been received from the joint Conference Committee, inviting the Society to become a charter member of the Federation, and that the Board of Government had referred the invitation to a committee for consideration. He then called on Mr. Weston, chairman of that committee, who presented the following report:

BOSTON, December 16, 1920.

THE BOARD OF GOVERNMENT,
BOSTON SOCIETY OF CIVIL ENGINEERS,
TREMONT TEMPLE, BOSTON, MASS.

Gentlemen, — Your committee, appointed to consider the advisability of the Society joining the Federated American Engineering Societies, has given careful consideration to the subject, including the hearing of an address by Mr. Herbert Hoover, the newly elected president of the federation, and reports as follows:

We believe that there exists a useful field for an organization whose object is "to further the public welfare wherever technical knowledge and engineering experience are involved, and to consider and act upon matters of common concern to the engineering and allied professions."

We believe the new association can become an instrument for informing the public regarding the functions and abilities of engineers, and the part they may play in the life of the world. It may also act as an instrument for expressing the common thought of the engineering profession.

We believe that the success of the new association will depend upon the character of its management; if unselfish, wise and conservative, the advantages to the member societies and the profession will be great; if selfish, foolish and radical, the federation will easily degenerate into a political machine of which the component parts may feel ashamed. However, the present management represents the best in the profession, and we believe that it is incumbent upon the Boston Society of Civil Engineers to join the federation if it be able to do so. It may do so with safety because the constitution of the Federated American Engineering Societies provides that any member society may withdraw on either June 30 or December 31 of any year by giving three months' notice, and by discharging its financial obligations.

The objections to joining are largely financial, but are so serious that

they must be overcome before the Society can accept membership in the new organization.

The budget for the current year shows that the expenses of our Society will exceed materially its anticipated current income, the estimated overdraft being substantially equivalent to the entire income accruing from the permanent fund this year.

If the Society should decide to join the Federated Societies, it would be necessary for it to raise, this year, approximately \$850 additional. The only methods available for doing this are, apparently, —

(a) The securing of additional members in sufficient number to overcome the present deficit by an amount equal to the dues of the Federated Engineering Societies.

(b) Abandonment of some of the present activities of the Society.

(c) Raising the dues of the Society by constitutional amendment.

Your committee feels that the abandonment or serious curtailment of any of the present activities of the Society would interfere with the efforts the Society is now making to promote the professional and social welfare of its members, particularly its younger members, to an extent which could not be compensated by any advantages likely to be derived from membership in the Federated Societies; that there is no prospect of securing additional members sufficient to accomplish the result stated under (a); that the Board would not be justified in advising membership in the Association unless it could feel sure that decreased membership and a reduction in the rate of growth would not follow a raise in the dues by constitutional amendment which is the only method for overcoming the financial obstacle which your committee can suggest.

In view of the above consideration, your committee is unanimous in recommending that our Society should not accept the invitation of the chairman of the Joint Conference Committee to join the Federated American Engineering Societies unless it is feasible to overcome the financial objection by adding one dollar per year to the dues, and in recommending that a questionnaire be sent out to ascertain the willingness of the members to bear the additional financial burden which membership in the new association would impose. Furthermore, it is the opinion of your committee that in judging the results of the canvass, and when taking further action, especial consideration should be given to the minority, some of whom might feel unable to continue their membership in the Society if the dues were increased.

Very respectfully,

(Signed) ROBERT SPURR WESTON.

(Signed) CHARLES M. SPOFFORD.

(Signed) FRANK O. WHITNEY.

At the conclusion of the reading of the report the President made a statement in reference to the finances of the Society for the present year and for the coming year.

Past President Charles T. Main then read a statement which he had prepared, on the origin, formation and objects of the Federated American Engineering Societies and the American Engineering Council, from which the following abstract has been made.

In 1918 the four founder societies, the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Electrical Engineers, and the American Institute of Mining and Metallurgical Engineers, each appointed committees to consider the internal affairs of the society and the external relations to the profession in general and to the public.

These four committees combined to consider external relations, and was known as a Joint Development Committee and was later known as the Joint Conference Committee. After careful deliberation and a vast amount of work, the Joint Conference Committee presented its report the latter part of the year 1919. This report was approved in principle by the four founder societies.

On January 23, 1920, a joint meeting was held of the Joint Conference Committee, the councils of the four societies, the American Society for Testing Materials, Trustees of United Engineering Society and Members of the Engineering Council, and it was resolved that the Conference approves in principle the report, and requests the Joint Committee to call, without delay, a conference of representatives of national, local, state and regional engineering organizations to bring into existence the comprehensive organization proposed.

An organization conference was held in Washington, June 3 and 4, 1920, at which were present representatives from more than seventy-five engineering societies, with an aggregate membership of more than 125 000.

At this meeting, "*The Federated Engineering Societies*" was organized.

The object of the federation is "to further the public welfare wherever technical knowledge and engineering experience

are involved, and to consider and act upon matters of common concern to engineering and allied technical professions."

Its *membership* is to "consist of national, local, state and regional engineering and allied technical organizations and affiliations."

The *management* is vested in a body known as American Engineering Council and its Executive Board.

The *representatives in the Council* are selected from the various member societies, each society being entitled to one representative for a membership of one hundred to one thousand and one additional for each additional thousand or fraction thereof.

The *Council* shall hold at least one meeting a year.

The *Executive Board* consists of thirty members, of whom six shall be the officers elected by the Council and twenty-four selected from the member societies. It shall meet at least bi-monthly, and will conduct the business of the federation.

This board is similar to the recent Engineering Council, and will carry forward the work of Council.

Funds to carry on the work will be contributed by the member societies, the national societies contributing \$1.50 and the local societies \$1.00 annually per member.

The membership of any constituent organization may be *terminated* on June 30 or December 31 of any year, by giving three months' notice.

Past President Metcalf followed with an urgent plea that the Society join the federation even if it were deemed best to meet the financial obligations by the curtailment of some of the Society's activities rather than by increasing the annual dues.

A very general discussion followed, in which Messrs. Fitzgerald, Larned, Bryant, Sanborn, Fales, Gunby and others took part. It was finally voted that it is the sense of the meeting that the Boston Society of Civil Engineers should join the federation, and that it is also the sense of the meeting that this should be done without increasing the annual dues.

It was also voted that the Board of Government be requested to arrange for the proper presentation of the matter at the next meeting of the Society.

At the request of some of the members, Past President FitzGerald gave further information relative to the Federal Water Power Act and the Society's resolutions now before the members for a letter-ballot. At 9.30 Vice-President R. S. Weston, who was in the chair, declared the meeting adjourned.

S. E. TINKHAM, *Secretary*.

APPLICATIONS FOR MEMBERSHIP.

[January 15, 1921.]

THE By-Laws provide that the Board of Government shall consider applications for membership with reference to the eligibility of each candidate for admission and shall determine the proper grade of membership to which he is entitled.

The Board must depend largely upon the members of the Society for the information which will enable it to arrive at a just conclusion. Every member is therefore urged to communicate promptly any facts in relation to the personal character or professional reputation and experience of the candidates, which will assist the Board in its consideration. Communications relating to applicants are considered by the Board as strictly confidential.

The fact that applicants give the names of certain members as reference does not necessarily mean that such members endorse the candidate.

The Board of Government will not consider applications until the expiration of twenty (20) days from the date given.

BURRAGE, HENRY THOMPSON, Cambridge, Mass. (Age 63, b. Roxbury, Mass.) Started in as rodman for Barbour and Hodges in 1874 and worked for them two years. In 1876 was employed by the city engineer of Cambridge, and has been in this office ever since, and at present is assistant engineer. Refers to Henry S. Adams, L. M. Hastings, G. Franklin Hooker and Charles A. Mason.

CRONIN, WILLIAM HENRY, Cambridge, Mass. (Age 47, b. Boston, Mass.) Graduate of Phillips Grammar and Boston Evening High schools. Employed continuously for the past twenty-five years with the Engineering Department of the Metropolitan Park Commission. At present is assistant

engineer in the Engineering Department, Metropolitan District, Park Division, and work consists of surveys and plans for acquirement and conveyance of land, lines and grades, estimates and inspection on roadways, bridges, seawalls, culverts,* etc. In 1906 was construction engineer, and 1907 construction inspector in U. S. Reclamation Service; 1909 C.E. Intercoastal Waterways; 1918 highway engineer, Bureau Public Roads, and chief of survey party, Construction Division of the Army. Refers to David A. Ambrose, Geo. W. Dakin, Carl S. Drake, D. J. Lynch, J. E. L. Monaghan and James E. Stone.

HAGGERTY, THOMAS JOSEPH, Boston, Mass. (Age 29, b. Boston, Mass.) Graduate of mechanical engineering in 1915, structural engineering in 1917, at Lowell Institute. Started engineering work in June, 1912, with Herbert S. Kimball, chemical plant and mill engineer, as detail draftsman for one year, draftsman three years and designing four years on wood, steel and reinforced concrete structures. Has been employed by Mr. Kimball, 75 State Street, Boston, for the past eight years. Refers to David A. Ambrose, William A. Brown, Walter B. Douglass and Herbert S. Kimball.

MIRABELLI, EUGENE, Dorchester, Mass. (Age 23, b. Boston, Mass.) Received S.B. in civil engineering at Mass. Institute of Technology, 1918, and certificate in naval architecture and ship construction in December, 1918, at M. I. T. Was with McClintic-Marshall Co., at Pittsburg, Pa., from January, 1919, to September, 1920, on structural steel work, including two months in fabricating shop; nine months in drafting room making shop drawings; six months in the field, and four months estimating and designing. In October, 1920, was appointed instructor in bridge design at Mass. Institute of Technology. Refers to Prof. J. B. Babcock, Prof. H. L. Bowman, H. M. Chadwick, J. C. Moses, A. P. Porter and Prof. C. M. Spofford.

MURPHY, JOHN JOSEPH, Boston, Mass. (Age 28, b. Boston, Mass.) Graduated from Mechanic Arts High School, Boston, 1911; from Lowell Institute "Buildings Course" in 1917. September, 1911, to June, 1912, with Fuller Whitney Survey Corp., 15 Court Square, Boston, as rodman and transitman; June, 1912, to the present with the City of Boston, Park Department, as rodman, transitman and assistant engineer, and in 1919 was appointed engineer of the Park Department, where he is at the present time. Refers to John E. Carty, William H. Ellis, Jr., Charles E. Houghton and Edward T. Murphy.

NOWELL, FRANK, J, West Roxbury, Mass. (Age 57, b. Kennebunkport, Me.) Began engineering about 1882, under Ed. Lydston, then on survey for beeline railroad, Boston to New York. Also with Frederick Law Olmsted, Brookline; Waring, Chapman and Farquhar, sanitary engineers, Newport, R. I.; also with City of Boston, Stony Brook Improvement, under Sidney Smith. In December, 1889, was appointed assistant engineer under Howard A. Carson, Metropolitan Sewerage Commission, and has worked ever since for the State Highway Commission, Metropolitan Park Commission, and now with the Metropolitan District Commission, Parks Division. Refers to David A. Ambrose, George W. Dakin, Edgar S. Dorr, Carl S. Drake, A. M. Lovis and John E. L. Monaghan.

SHAW, PERCY A., Manchester, N. H. (Age 36, b. Athol, So. Dak.) Graduated from Brown University in 1908, with B.S. in civil engineering. Spent four summers on engineering work; 1908-1909 was at Lancaster, Pa., with F. H. Shaw, cons. municipal engineer; 1909-1912, railway engineer in charge of branch office for F. H. Shaw, on design and construction of bridges, sewerage and water works; 1912-1917, principal assistant engineer with F. H. Shaw, in charge of office, designing and supervising construction of water supply, sewerage works, bridges, etc.; 1917 to date with L. H. Shattuck, Inc., designing and constructing industrial buildings. Hydroelectric plants, dams, etc. Refers to H. K. Barrows, Arthur C. Eaton, C. H. Pierce, G. G. Shedd, R. S. Weston.

SHEA, JOSEPH THOMAS, Cambridge, Mass. (Age 23, b. Cambridge, Mass.) Educated at Rindge Technical School, 1913-1917; George Washington University, 1918-1919. At present attending evening school at Mass. Institute of Technology. At present, draftsman in office of principal assistant engineer, Boston & Albany R. R. Refers to L. G. Brackett, T. P. Perkins, A. S. Tuttle, J. J. Rourke.

SMITH, MERRITT PARKER, Arlington, Mass. (Age 23, b. North Scituate, R. I.) Graduated from Mass. Institute of Technology with class of 1919. Was junior highway engineer with the state of Illinois from June, 1919, to Sept., 1920. Appointed instructor at Technology, Sept., 1920. Refers to Prof. J. B. Babcock, Prof. C. B. Breed, Prof. Dwight Porter and Prof. C. M. Spofford.

WATSON, GEORGE NEWELL, Watertown, Mass. (Age 19, b. Manchester, Mass.) Since 1918 has been employed by the Town of Watertown, Engineering Department, general office and field work under Wilbur F. Learned and Forrest J. Maynard. Is attending Northeastern College, evening school of engineering, taking a three-year course. Is at present working in the engineering department; Watertown, Mass. Refers to W. E. Eberhard, Wilbur F. Learned, Forrest J. Maynard and H. A. Maynard.

LIST OF MEMBERS.

ADDITIONS.

KENT, SILAS STANLEY.....66 Broadway, Lowell, Mass.
MURPHY, DANIEL A.....17 Kenburma Rd., Dorchester, Mass.
PATTERSON, HERBERT L.....23 Playstead Rd., Boston 25, Mass.
RICHARD, WALTER C.....390 Front St., Weymouth, Mass.

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11*

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GREEN, HOWARD W.....	International Health Board, Central Aquirre, P. R.
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HARTY, J. J.....	Care Monks & Johnson, 99 Chauncy St., Boston, Mass.
HURD, STEPHEN P.....	Room 304, 4500 Euclid Ave., Cleveland, Ohio
KITFIELD, EDWARD H.....	Swampscott, Mass.
MORPHY, LUIS G.....	Chief Engineer, Rutland Railroad, Rutland, Vt.
PRICE, HERMAN S.,	
	U. S. Geol. Survey, Montana National Bank Bldg., Helena, Mont.
SPEAR, WALTER E.....	Merrick, N. Y.
STARR, J. A.....	28 Playstead Rd., Dorchester, Mass.
STEARNS, RALPH H.	P. O. Box 1129, Boston, Mass.
THORPE, L. D.....	Room 1129, Old South Bldg., Boston, Mass.

DEATH.

BLAKE, EDMUND M.	January 12, 1921
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LIBRARY NOTES.

BOOK REVIEW.

HANDBOOK OF BUILDING CONSTRUCTION: By Hool and Johnson, Consulting Engineers. First edition. First impression, New York, McGraw-Hill Book Co. Leather, 6 x 9 in.; 2 vols., pp. 1 474, figures and tables.

REVIEWED BY J. R. WORCESTER.

The title of this book of nearly 1 500 pages, 6 in. by 9 in., in two volumes, is somewhat misleading if one is looking for a condensed collection of data. If, however, he is seeking a comprehensive compilation touching every phase of building construction, this work will be likely to please him. The authors have had the assistance of forty-six specialists, each of whom has written one or more sections. While this method of securing expert knowledge in a great variety of fields has its manifest advantages, it inevitably disturbs the consistent, consecutive arrangement which the work of one head would have developed.

It seems to a casual reader as if it had involved needless repetition, not of words or data, but of lines of thought upon similar subjects, treated in different chapters when they might have been combined.

An awkward feature of the book is the necessity of using both volumes together, the table of contents for both being in the first and the index for both in the second. If the matter could have been completely divided so that each volume would have been self-contained, it would generally be necessary to refer to only one to obtain the desired information. Then, again, one misses a systematic grouping of subjects which would enable him to turn, without studying a table of contents, to the approximate place in the book where he might find what he wants. This difficulty will, of course, grow less with greater familiarity with the book.

It would be hard to think of any branch of building construction which is not covered more or less fully. Some features are given in most explicit detail, with illustrative examples, though others are treated somewhat superficially. In places, the reader is apparently assumed to be a beginner, who requires enlightenment on most elementary points; while in others the subject is treated on a plane altogether above the comprehension of a novice. It would no doubt be impossible to cover the whole field as thoroughly as some parts are covered, and even upon the subjects less thoroughly covered there will always be found information which will be useful to many.

Much data needed by structural engineers is given in tabular form, which has never been before collected in so small a space, if, indeed, it has ever been published. This compilation of data is enough, even without the descriptive matter, to give the book a great value. Moreover, the excellence of the typography — barring a few errors which will no doubt be corrected in later editions — and the clearness of the illustrations, leave nothing to be desired, and increase the satisfaction with which the work will be consulted.

RECENT ADDITIONS TO THE LIBRARY.

U. S. Government Reports.

Structure and Oil and Gas Resources of the Osage Reservation, Oklahoma. Bulletin 686-Y.

Mortality Statistics, 1919.

Municipal Reports.

Cambridge, Mass. Report of Water Department for year ending March 31, 1919.

New Bedford, Mass. Report of Engineering Department 1919.

Newton, Mass. Report of Engineering Department. 1919.

Miscellaneous.

Handbook of Building Construction. Hool & Johnson. 2 vols.

Life in a Large Manufacturing Plant. Charles M. Ripley.

BOSTON SOCIETY OF CIVIL ENGINEERS
FOUNDED 1848

PAPERS AND DISCUSSIONS

This Society is not responsible for any statement made or opinion expressed in its publications

WATER-POWER DEVELOPMENT IN NEW ENGLAND.

By H. K. BARROWS,* MEMBER BOSTON SOCIETY OF CIVIL ENGINEERS.

(Presented December 17, 1920.)

SCOPE OF PAPER.

At the present time the total use of power in the United States for manufacturing and in power stations is over 40 million h.p., of which about 8 million h.p., or approximately $1/5$, is water power. Over a million horse power of this water power is developed here in New England — in fact, considered as a unit (which would be fair in respect to area), New England leads in the amount of developed water power, the states of New York and California following in the order named.

While the larger amount of undeveloped water power is in the West — roughly, 70 per cent. of the *developed* power being east of the Mississippi River and 70 per cent. of the undeveloped power *west* of the Mississippi — there is still much opportunity for water-power development here in New England, as well as the improvement and fuller development of power sites not wholly or efficiently utilized.

It is the general purpose of this paper to review the present situation in regard to the amount and distribution of water power in New England, both developed and undeveloped, the basis for its development and use, its relative economy and the

* Consulting Engineer, 6 Beacon Street, Boston, Mass.

possibilities of improvement in the way of storage projects and redevelopment, as well as to outline some of the difficulties which at present discourage comprehensive action.

ELEMENTS AFFECTING THE VALUE OF THE POTENTIAL WATER POWER OF NEW ENGLAND.

Reduced to its basic elements, potential water power depends upon the stream flow or quantity of water available and the head or fall through which the water may be utilized, — both of these elements depending fundamentally upon natural conditions. A discussion of these elements with particular reference to New England is therefore pertinent to show the basis for the important position held by water-power development in these states.

PRECIPITATION.

Amount and Variation. — The amount and distribution of precipitation is of course of fundamental importance in affecting the flow of streams. By reference to Fig. 1 it will be noted that the mean annual precipitation varies from about 32 ins. in western Vermont to a maximum amount of about 84 ins. at the summit of Mount Washington, the average for New England being probably between 40 ins. and 45 ins. A study of this map indicates that, in general, along the coast for a short distance inland the precipitation is greater than further inland or a short distance seaward. Still higher amounts are found in the elevations of the White and Green Mountains and the Berkshires, while beyond these ranges in western and northern Vermont and northern New Hampshire and Maine the least amounts occur.

Effect of Altitude. — The effect of altitude upon precipitation is marked in the Connecticut and Merrimack River basins on the *coastal* side of the White and Green Mountains, as will be noted on Fig. 2, where a plot of altitude — precipitation shows an approximate relation $P = 35 + 7.5A$, where P = mean annual precipitation in inches and A = altitude in thousands of feet. This plot also shows the lack of precipitation data for elevations over



FIG. 1. — NEW ENGLAND ANNUAL PRECIPITATION IN INCHES.

1 000 ft.,—an unfortunate gap in our basic information upon precipitation, only imperfectly bridged over by such studies as Fig. 2, which can safely be applied only in limited areas.

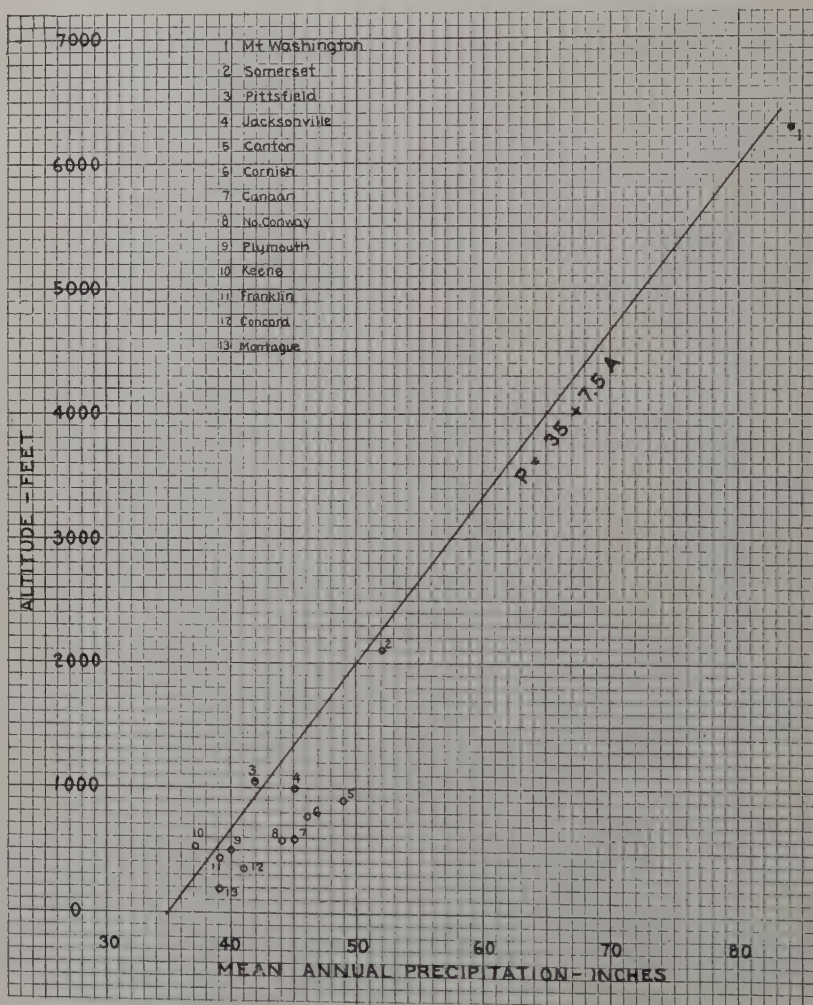


FIG. 2. — EFFECT OF ALTITUDE ON PRECIPITATION.

Variation of Mean. — The precipitation data on Fig. 1 are from records of various lengths, most of which are, however, for a sufficient length of time to give a fair determination of the mean. On Fig. 3 is shown for a number of the longer records the

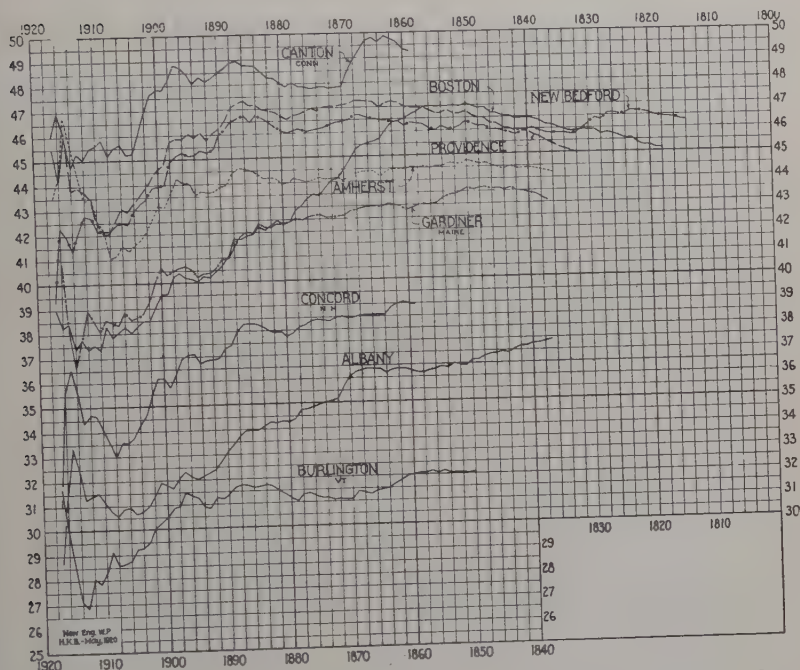


FIG. 3.—PRECIPITATION IN NEW ENGLAND. VARIATION IN YEARLY MEAN.

variation in the yearly mean from 1917 backwards. In general, a deficiency in precipitation as regards the long-time mean has occurred during the last twenty to thirty years, as will be noted by the following:

Station.	Year of Equal Progressive Mean and Long-time Mean.
Boston.....	1869
New Bedford.....	1889
Providence.....	1899
Amherst.....	1897
Gardiner (Me.).....	1863
Concord (N. H.).....	1862
Albany.....	1837
Burlington (Vt.).....	1860 ±

The Boston record shows a deficiency since about 1869, while the deficiency at Amherst reaches back only to 1897, the

latter record showing much less variation than that of Boston. New Bedford and Providence are fairly consistent with Amherst, while Albany and Burlington show in general a progressively declining precipitation since the beginning of the records.

As most of the records of stream flow in New England are not available before 1900—and many not even then—it is evident from Fig. 3 that they represent in general a period below the average in precipitation and therefore in all probability also in run-off of streams.

Variation during Year.—Precipitation in New England is in general fairly evenly distributed through the year, as will be

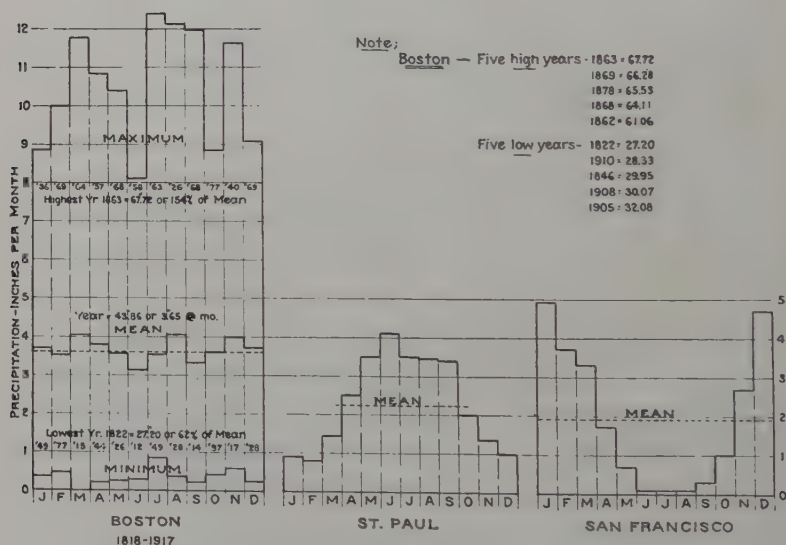


FIG. 4. — VARIATION IN MONTHLY PRECIPITATION.

noted by reference to Fig. 4, where is shown the mean, minimum and maximum precipitation at Boston by months of the year. The mean monthly precipitation is 3.65 ins., varying from 3.11 ins. (or 15 per cent. from the mean) in June to 4.04 ins. (or 10 per cent.) in both March and August.

Fig. 4 also shows for comparison the monthly mean precipitation at St. Paul and San Francisco, both of which show great variations in precipitation during the year, as well as a much less average amount than Boston.

Single months will show great variations in precipitation. Thus in March, 1915, there was no measurable amount (see Fig. 4), and minima of 0.2 in. to 0.5 in. have been reached by all months but July. A maximum of 12.38 ins. was recorded in July, 1863, and many other months have shown maxima over 10 ins. It is also noteworthy that no maximum has occurred subsequent to 1877, while minima for four months of the year have occurred since 1911.

RUN-OFF OR STREAM FLOW.

General Tendencies. — The water flowing in the rivers and streams is chiefly the residual of precipitation and the water losses due (1) to soil evaporation, (2) interception by vegetation and growing crops and (3) transpiration or water requirements of vegetation and crops. Seasonal variation also occurs in the ground-water level, this "ground storage" in a dry season furnishing much of the minimum flow of the stream. Snow storage also modifies and retards run-off, tending to concentrate it in spring floods or thaws.

As a result of these various tendencies, a stream like the Nashua River, with an average yearly precipitation of about 45 ins., will afford in the six months December to May, inclusive, about 16.7 ins., or 75 per cent. of the average total yearly run-off of about 22 ins.

During each of these six-month periods the precipitation is practically the same, viz., 22.5 ins., and hence the proportion of precipitation appearing in the stream is about 75 per cent. during the winter six months and only about 25 per cent. during the summer six months. The distribution of run-off during the season is thus much more irregular than that of precipitation.

The average yearly land water losses or retention for a given river basin do not vary as greatly as either precipitation or run-off, tending in general to increase somewhat with the amount of

precipitation. Thus, for the Nashua River rough annual values would be:

Precipitation. Inches.	Water Losses. Inches.	Run-off. Inches.
50	24	26
45	22.5	22.5
40	21	19

Individual years will of course show considerable variations, due chiefly to differences in distribution of the precipitation; individual months still greater variations; the above is simply to illustrate tendencies.

Evaporation from water surface is usually much greater than the land water losses, varying from about 40 ins. in southern New England to 25 ins. per year in the northern and more elevated regions, as shown by such measurements as are available. The introduction into a drainage area of a large reservoir for storage purposes tends therefore to reduce the total or average yield of the basin.

Precipitation can be observed without difficulty, but the land water losses or retention cannot be comprehensively measured. Hence, to determine with the necessary accuracy the water available for power developments, stream flow must be measured by days and months over as long a period as possible.

Essentials of Stream Flow Required for Water-Power Developments. — To properly lay out a water-power development the following stream flow data are needed:

(1) Low-water flow as a basis for the amount of primary or dependable power and (often) size of steam auxiliary.

(2) Daily flow over a period of years, as a basis for plant capacity and estimated output.

To permit of the study of storage projects the records should cover a dry period of years.

(3) Flood flow, to enable a safe installation with adequate spillway or gate relief.

Available Records of Stream Flow in New England. — Aside from a few excellent records of stream flow maintained by state and municipal authorities and private companies, data of stream

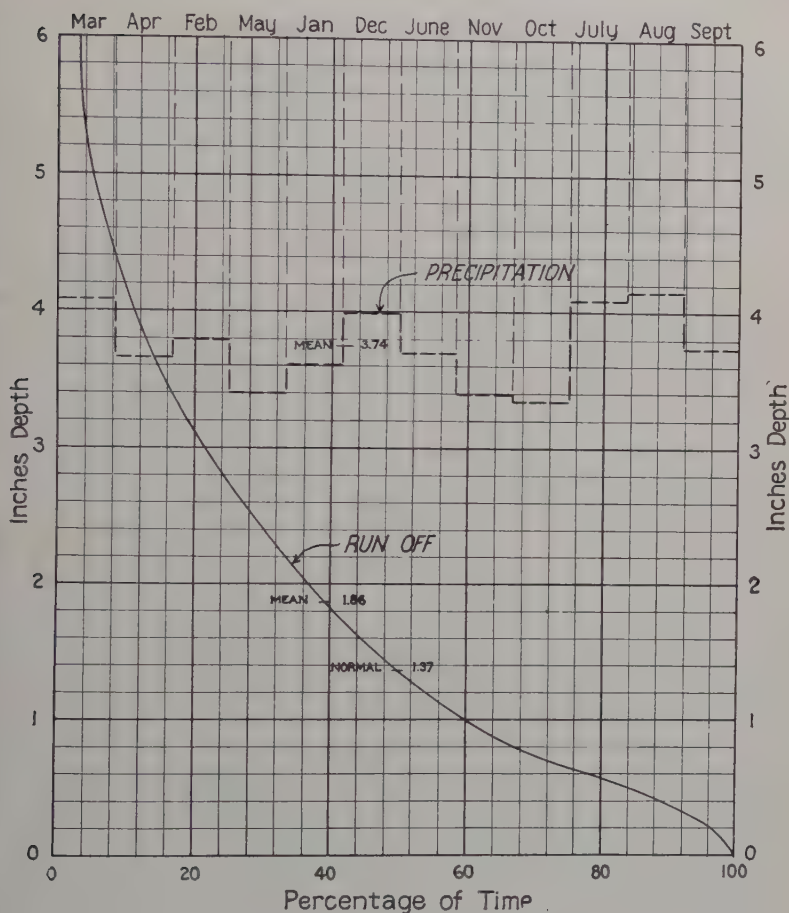


FIG. 5. — NASHUA RIVER AT WACHUSETT RESERVOIR, PRECIPITATION AND RUN-OFF, 1897-1919.

flow are now being obtained almost wholly by the Water Resources Branch of the U. S. Geological Survey, under a small federal appropriation, supplemented in several cases by state funds. For many years Congress appropriated only \$150 000 annually for such work, covering the whole United States, and even now this amount is only \$175 000, — an absurdly small appropriation for such important work.

The available stream-flow records extend back to 1900 only in a few cases, and the majority cover perhaps five to ten years. At present, some 53 river stations are being maintained in New England, of which 22 are in the state of Maine. It is of great importance to the further development of water power that this river-gaging work be continued without interruption, and if possible with a wider scope.

Relative Yield of New England Streams. — To ascertain the flow available and its variation during the year, for use in water-power studies, flow-duration curves are prepared, in which for the period of time covered by the records the various amounts available by months (or sometimes weeks and days) are arranged in order of magnitude for the entire period, independent of calendar order. This curve shows the flow available for any given percentage of time and serves as a basis for the determination of the proper amount of wheel capacity and average power output.

On Fig. 5 is such a curve for the Nashua River, on the basis of monthly yield for the period 1897-1919, inclusive. The *mean* run-off of 1.86 ins. per month is available (or exceeded) about 39 per cent. of the time, while for a small per cent. of time the run-off is practically zero, due to the considerable water area, about 7 per cent. (and therefore evaporation), of the Wachusett Reservoir. It is also to be noted that the normal (or 50 per cent. value) is 1.37 ins. per month, — an amount perhaps more logically representing the power value of the natural stream or of rivers where storage possibilities are limited. On Fig. 5 is also shown the order of months of the year in amount of run-off, and the average precipitation for each month. As previously noted, for Boston there is no great difference in average precipitation by months, but run-off shows a much greater variation.

On Fig. 6 are shown flow-duration curves for some typical New England streams, varying from the comparatively high average yield of the Deerfield River to the low yields of Otter Creek and of the Merrimack at Lawrence. These are based upon monthly flow except in the case of the Merrimack, which is by weeks. In the case of the Deerfield and Nashua rivers,

STREAM	LOCATION	YEARS	MEAN
Otter Creek	Middlebury, Vt.	1910-11-1915-16	1.49
Merrimack	Lawrence	1880-1914	1.48
Connecticut	Orford	1900-1-1918-19	1.75
"	Sunderland	1904-5-1918-19	1.65
Nashua	Wachusett Res.	1897-1919	1.65
Deerfield	Charlemont	1913-14-1918-19	2.36

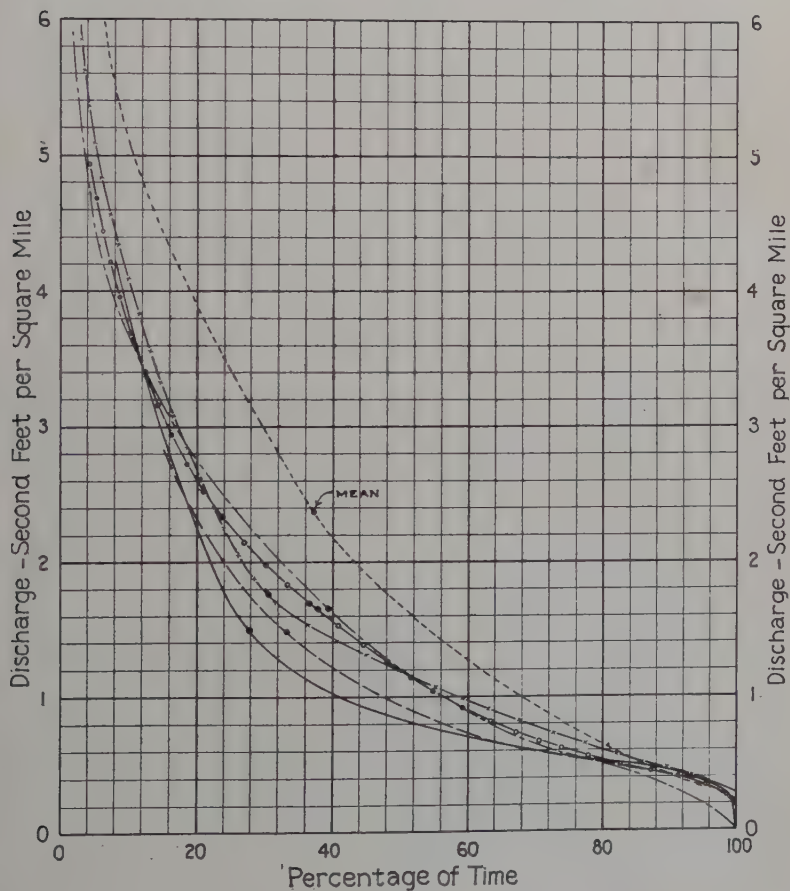


FIG. 6. — FLOW DURATION CURVES FOR TYPICAL NEW ENGLAND STREAMS.

correction for stored water held or released has been made, so that all these curves represent approximately natural run-off, although, particularly in the case of the Nashua River, the yield during the drier months of the year is considerably lowered by evaporation from water surface. While owing to lack of data these curves are for different periods of years, they give a good idea of variations to be expected in different parts of New England and show clearly the need of obtaining stream-flow data as directly applicable as possible to a given water-power project, in order to avoid serious discrepancies in power estimates.

NATURAL CONDITIONS AFFECTING WATER-POWER DEVELOPMENTS IN NEW ENGLAND.

The water-power resources of an area are largely dependent upon its geology, and the many opportunities for water-power and storage development in New England at reasonable cost are due fundamentally to favorable geological conditions. Thus, with the Kennebec and other important power streams in Maine glacial occupation of the drainage basin is largely responsible for the various water-power sites, defined by ledge outcrop (which in the typical case affords a concentrated fall succeeding a quiet stretch of river, thus affording a good "mill pond"), and also for the many natural lakes and storage basins which aid in making more constant flows of the streams.

The total area of New England is about 66 000 sq. miles, of which one half comprises the state of Maine. As a unit, New England has a little less area than Washington state (69 000 sq. miles) and a little over one third of that of California (158 000 sq. miles). Its limited area is offset as regards potential water power by the large amount of fall of its streams and consequent head available for development. In the following table are given data of fall and drainage area for a few important power streams, illustrating this feature.

RIVER.	DISTANCE IN MILES FROM MOUTH OF RIVER TO REACH VARIOUS ELEVATIONS AND CORRESPONDING D. A. SQ. MILES.					
	500 Ft.		1 000 Ft.		1 500 Ft.	
	Dist. Miles.	D.A. Sq. Miles.	Dist. Miles.	D.A. Sq. Miles.	Dist. Miles.	D.A. Sq. Miles.
Connecticut . . .	270	2 000	345	350	365	90
Deerfield	30	370	45	222	60	45 ±
Kennebec	90	2 500	120	1 250	...	...
Penobscot	103	1 600	140 ±	800 ±	...	...
Androscoggin . .	83	2 090	135	1 350	...	...

To summarize, natural conditions are favorable for water-power development in New England, with many good dam and reservoir sites, relatively high river slopes and in general a well distributed rainfall averaging from 30 ins. to 50 ins. per year.

FLOW BASIS USED IN WATER-POWER DEVELOPMENTS.

The extent to which the flow of a stream can be utilized is a question of economy, in its broad aspect depending upon the relation of cost of development and value of the power developed, both of which are affected, in the case of power plants, by the extent to which the power demand varies — or, in other words, the load factor. Ideally, the limit in cost of plant will be reached when the increment in plant cost just equals the value of the increment of power gained. Practically, the problem is often indefinite owing to the uncertainty of costs or of power value, and the extent of power development must be a matter of judgment and experience. It must also be kept in mind, in comparing installations, that actual wheel capacity will also depend upon load factor and allowance for spare units. Furthermore, where power is used chiefly during the working day, as in cotton and woolen manufacture, and good pondage is available, a high wheel capacity is required to utilize the twenty-four hour flow in perhaps one third of that time.

To indicate the actual range in capacity of existing developments in New England, Table I has been prepared, covering some

TABLE I.
INSTALLED WHEEL CAPACITIES AT NEW ENGLAND PLANTS.

River.	Location.	Use.	Drainage Area. Sq. Mi.	H.P. Wheels.	Approx. Capacity of Wheels. Sec. Ft. per Sq. Mi. (Generally 80% eff.)	Remarks.
Union.....	Ellsworth, Me.	El. Power	537	3 000	1.06	Proposed, 48 000 h.p., or 2.46. Two adjacent plants, Montpelier and Barre L. & P. Co. Now under construction. Large storage. Storage and high head (676 ft.). Average, 4 plants, N. E. P. Co. Plants of Athol, G. & El. Co.
Androscoggin....	Rumford Falls, Me.	do.	2 090	30 000	1.45	
Saco.....	W. Buxton, Me.	do.	1 550	4 000	1.15	
Presumpscot....	Great Falls, Me.	do.	438	3 500	2.64	
Merrimack.....	Garvins Falls, N. H.	do.	2 340	6 000	1.00	
Connecticut.....	Vernon, N. H.	do.	6 300	32 000	1.64	
Connecticut.....	Turners Falls, Mass.	do.	7 100	67 500	2.05	
Winooski.....	Montpelier, Vt.	do.	196	1 650	1.32	
Otter Creek.....	Near Middlebury, Vt.	do.	650	4 000	2.05	
Leicester.....	Salisbury, Vt.	do.	30	2 200	4.50	
Silver Lake.....	Near Salisbury, Vt.	do.	19	4 000	3.40	
Deerfield.....	Shelburne Falls and above, Mass.	do.	...	52 800	3.80	Mfg. jute goods, Ludlow Co. Cotton, woolen, paper mfg., etc. Paper mfg., H. & W. Co. Paper mfg., G. N. P. Co.
Millers.....	Farley, Mass.	do.	384	435	0.78	
Millers.....	Wendell, Mass.	do.	353	2 200	3.27	
Chicopee.....	Red Bridge, Mass.	Power for Mfg.	664	7 300	2.42	
Merrimack.....	Lawrence, Mass.	do.	4 452	25 500	2.25	
Kennebec.....	Madison, Me.	do.	3 200	7 700	0.94	
Penobscot.....	Millinocket, Me.	do.	1 880	24 600	1.31	

of the important power installations and a few manufacturing plants.

Reference to Table 1 and Fig. 6 indicates that water-power plants in system, particularly where steam auxiliary is available, show wheel capacities approximating the flow available 25 per cent. of the time. This is illustrated by the Deerfield and Vernon developments of the New England Power Company and several others. Nearly all the hydroelectric stations show wheel capacities in excess of the 50 per cent. flow.

FLOW BASIS USED IN WATER-POWER ESTIMATES.

In the estimates of available water power made by different state commissions there has been considerable latitude in the extent of development assumed. Thus *Maine** used an assumed development for a flow available 60 per cent. of the time (New York — Conservation Commission also using this basis); *Massachusetts*† used the *mean* flow (or approximately the 33 per cent. flow); *New Hampshire*‡ used the 50 per cent. flow.

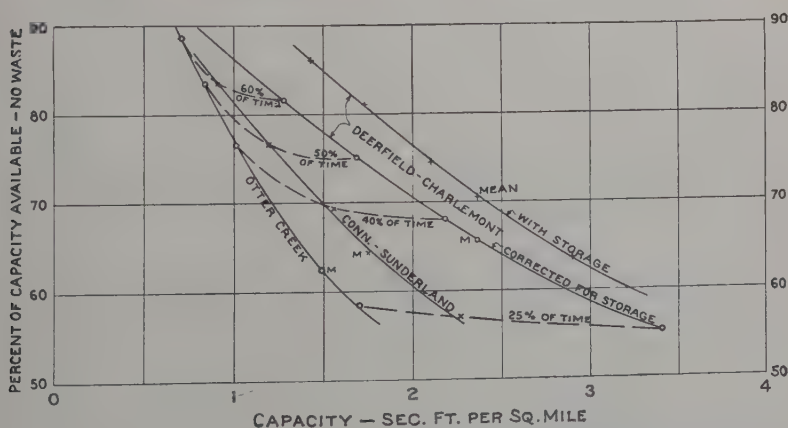


FIG. 7. — RELATION OF CAPACITY AND WATER AVAILABLE WITH NO WASTE OF WATER.

To better illustrate this matter, Fig. 7 has been prepared, based upon certain curves in Fig. 6. Assumed wheel capacity

* Public Utilities Commission, 1918.

† Commission on Waterways, 1918.

‡ Commission on Water Power, 1918.

is plotted against the per cent. of that capacity available, assuming no water wasted. Limiting curves for Otter Creek (low) and Deerfield River (high), as well as a curve for Connecticut River which is fairly intermediate between the first two, are shown. Dotted lines, approximately horizontal, also indicate capacity expressed as a per cent. of time when available.

For the Connecticut at Sunderland (or the approximate average stream) the following appears from the curve:

Assumed Plant Capacity. (100% L. F.) Sec. Ft. Sq. Mi.	Per Cent. of Time Available.	Average Flow Available, No Waste.		Per Cent. of Time on Duration Curve Corresponding to Previous Column.
		Per Cent. of Capacity.	Sec. Ft. Sq. Mi.	
2.25	25	57	1.28	48
1.75 (mean)	38	65	1.14	52
1.50	40	70	1.05	54
1.20	50	76	0.91	60
0.91	60	87	0.79	65

Thus, without any waste, a river like the Connecticut developed up to the 25 per cent. flow point, will provide about 57 per cent. of that flow, which corresponds numerically to the flow available about 48 per cent. of the time, or 1.28 sec.-ft. per sq. mi. The Deerfield River developed to this same 25 per cent. flow would average about 55 per cent. of its capacity (without waste), or about 2.10 sec.-ft. per sq. mi. (the 40 per cent. flow point), reflecting the higher yield of this stream.

Waste of water — usually expressed as a “utilization factor” — may be considerable where many plants are located on a stream, and there is lack of pondage at or near the plant in question, and may readily amount to from 10 to 25 per cent., or even more in unfavorable cases.

In estimating available water power in general for New England, allowing for the various elements mentioned above, an assumed wheel capacity (at 100 per cent. L. F.) corresponding to the flow available about 40 per cent. of the time seems reasonable,

which would, with the typical duration curve, afford an average output of about 70 per cent. of this capacity, with no allowance for waste of water. If storage is available in considerable amounts, its use will materially increase the percentage of output to capacity of plant, as further noted.

Obviously, in designing new plants, each case must be studied by itself as previously noted, in order to arrive at the proper wheel capacity.

AMOUNT OF WATER POWER IN NEW ENGLAND.

Basis for Estimates. — Fairly accurate data of the amount of water power, both developed and undeveloped, are available for the states of Maine, New Hampshire and Massachusetts, based upon the following reports:

Maine: Special Report on Water Power, Public Utilities Commission, 1918.

New Hampshire: Report of Commission on Water Power, 1918.

Massachusetts: Report of Waterways Commission, 1918.

For the other New England states estimated amounts of power have been based upon the best information available, consisting of the 1914 U. S. Census of Manufactures, the 1916 Report of the U. S. Forest Service on Electric Power Development, the 1917 U. S. Census Bulletin on Central Electric Light and Power Stations, etc., as well as information gathered by and in the files of the writer.

Developed power is based upon existing wheel capacity, which, particularly in the state of Maine, does not represent the full extent to which sites could be developed. The amount of undeveloped power is adjusted as far as practicable to accord with the flow available 40 per cent. of the average year.

Amount of Water Power by States. — Details of developed and undeveloped water power by states are given in Table 2, where is also shown, for comparison, the total power, including that used for manufacturing and electric power, which would include steam, water and less important prime movers.

As will be noted from Table 2, the developed water power in New England is about 1 170 000 h.p., the undeveloped

867 000, and the total a little over 2 000 000 h.p., averaging about 31 h.p. per square mile of area. The total power, including steam, water, etc., is nearly 5 000 000 h.p., of which almost exactly one half is in use in the state of Massachusetts.

Approximately 25 per cent. of the total power used in New England at the present time consists of water power, and full water-power development would represent only about 40 per cent. of the present total power needs.

The great portion of the undeveloped water power, about 55 per cent., is in the state of Maine, with about 22 per cent. in New Hampshire and the remainder in the other states. The estimates for Vermont of undeveloped power are probably, if anything, too low, as available information is rather meager for this state.

RELATIVE ECONOMY OF WATER AND STEAM POWER.

Cost of Water Power. — The first cost of a hydroelectric plant (to which type of water-power plant this discussion will be confined) is greater per horse power than that of a steam electric plant, except where the natural opportunities for water-power development are very favorable.

The manner in which a water power is developed, as well as its cost, depends largely upon what may be called "the natural conditions," such as the amount of fall in the river, its degree of concentration, the size of the river or amount of water available for power, the availability of good foundations for a dam and the character of the topography adjacent to the river, with particular reference to the economical location of canals and penstocks.

Where fall is well concentrated and conditions of flowage permit, the simplest and most economical method of development is to build a dam with the power house at one end (or sometimes in the dam itself), simply utilizing the fall developed by the dam. For heads up to the vicinity of 30 ft. such developments can be made with the turbines placed in open wheel pits. Above this amount of head the cost of the bulkhead walls is likely to be such that a more economical development is made by bringing the water through short penstocks (or pipes under pressure) to the wheels. Frequently, natural conditions are

TABLE 2.
NEW ENGLAND — WATER POWER.

State.	Developed H.P.		H.P. Undeveloped.	H.P. Total.	Area Sq. Mi.	H.P. per Sq. Mile of Total Water Power.
	Mfg.	Electric.				
Me.....	250 000	130 000	482 000	862 000	33 040	26
N. H.....	120 000	80 000	190 000	390 000	9 305	42
Vt.....	50 000	70 000	120 000	200 000	9 565	21
Mass.....	200 000	130 000	330 000	410 000	8 315	49
R. I.	35 000	5 000	5 000	45 000	1 250	36
Conn.....	70 000	30 000	30 000	130 000	4 990	26
Total.....	725 000	445 000	1 170 000	2 037 000	66 465	31

NEW ENGLAND — TOTAL POWER AND POPULATION.

State.	Mfg. Total H.P. 1914.	Elec. Total H.P. 1917.	Total H.P. Mfg. and Elec.	Population, 1920.	Increase in Population, 1910-20. (%)
Me.....	487 211	143 796	631 007	768 014	3.5
N. H.....	344 093	97 313	441 406	443 083	2.9
Vt.....	173 937	82 154	256 091	352 421	1.0
Mass.....	1 396 722	1 015 075	2 411 797	3 852 356	14.4
R. I.	269 854	191 171	461 025	604 397	11.4
Conn.....	453 812	259 231	713 043	1 380 585	23.9
Total.....	3 125 629	1 788 740	4 914 369	7 400 856	12.9

such that it is more economical to carry the water in a canal or closed penstock for some distance along the river below the dam, rather than to obtain the full fall by means of the dam. This is likely to be the case where there are limitations to the height of the dam on account of resulting damage due to flowage.

Whether or not such development will be made by means of a canal or penstock depends largely upon the size of the river, viz., the amount of water to be carried. For a large stream (perhaps for quantities of flow in excess of 500 or 600 cu. ft. per sec.) it is usually more economical to use a canal, for the necessary size of penstock required increases quite rapidly with the quantity of water to be carried, and the cost of very large penstocks is relatively much greater than for smaller ones.

With large rivers, however, it is often desirable on account of the topography of the river banks to carry the water the greater part of the distance in a canal with small slope, and then for a short distance in penstocks (usually one for each wheel unit) which drop rapidly from the canal level at its end or "fore bay" to the wheel units at the level of the power house.

The main features of a hydroelectric development may therefore be divided into —

- (1) Dam.
- (2) Waterways — either canal, penstock or a combination of these.
- (3) The power house, including its foundations and tailrace.
- (4) The equipment, which may be further subdivided into hydraulic and electrical.

Obviously, the general items which will most affect the cost of a water-power development are those of the dam and waterways (and occasionally the tailrace). Where natural conditions are such that these features of the development can be made at low cost, the resulting total cost of development will be low, as in general the other features (power house and equipment) will vary in cost within a comparatively narrow range.

Cost of Water-Power Developments. — The total cost per horse power of capacity of water-power plants will vary (based on approximate pre-war costs) from about \$50 to \$60 per horse

power in extremely favorable developments upwards, an upper limit of about \$250 per horse power usually resulting in a cost of power output (including fixed charges, operating and transmission costs as further explained) about equal to that of a good-sized modern steam plant. Investigations made for the Public Utilities Commission of the State of Maine in 1918, covering the cost of both developed and undeveloped power on the principal rivers of the state, showed an average cost per horse power developed of about \$114, while the undeveloped was estimated at about \$99 per horse power. Further details of these estimates are appended hereto (Table 3), which were on the basis of a development to an amount of flow available 60 per cent. of the time after regulation by storage and with a 100 per cent. load factor. It should also be kept in mind that these power sites in Maine are among the best in New England, now undeveloped, and sites in most of the other states will show a much higher cost of development.

Effect of Load Factor on Cost of Development. — We may logically include the cost of dam (including land and water rights) and waterways (and perhaps of power-house foundations and tailrace, if these are features of importance or of unusual construction) in an item which may be called "construction cost" and which reflects particularly the relative advantage or disadvantage of the power site. The remaining costs, which may be called "power house and equipment," will obviously vary almost directly with the extent to which development is made, or more particularly the load factor for which the plant is designed.

To indicate the extent to which load factor affects the first cost of plant, Table 4 has been prepared. In this table extremes in cost of development have been assumed (through a range that would include "war costs") with the usual variation in cost of equipment and power house, and the relative costs of such plants with varying load factors are given with the per cent. increase in cost over that for a load factor of 100 per cent. Through the range of costs given, as will be noted, the increase in cost is approximately 3 to 8 per cent. for 80 per cent. L. F., 12 to 33 per cent. for 50 per cent. L. F., and 28 to 78 per cent. for 30 per cent. L. F.

TABLE 3.
SUMMARY OF COST OF DEVELOPED AND UNDEVELOPED WATER POWER.

RIVER.	60% H.P. OF CAPACITY AFTER STORAGE REGULATION.				COST OF POWER.			
	At Developed Sites.	At Undeveloped Sites.	At Both.	Total.	Developed.		Undeveloped.	
					Per H.P.	Total.	Per H.P.	Total.
Presumpscot.....	16 770	0	16 770	\$2 561 000	\$153	..	..	\$153
Union.....	6 530	0	6 530	334 000	51	..	..	51
Kennebec.....	63 900	169 560	233 460	9 600 000	150	\$100	\$17 092 000	114
Androscoggin *	118 020	42 770	160 790	14 200 000	120	134	5 730 000	124
Penobscot.....	158 310	94 560	252 870	14 200 000	90	76	7 150 000	84
Saco *	30 070	17 070	47 140	3 900 000	130	116	1 978 000	125
Total or Weighted Ave.	393 600	323 960	717 560	\$44 795 000	\$114	\$99	\$31 950 000	\$107
								\$76 745 000

* In the state of Maine only.

TABLE 4.
EFFECT OF LOAD FACTOR ON COST OF HYDROELECTRIC PLANTS.

COST OF PLANT TO DELIVER 1 H.P. ON WHEEL SHAFT WITH DIFFERENT LOAD FACTORS						PER CENT. INCREASE IN COST OVER THAT FOR 100 PER CENT. L. F.		
100 Per Cent. L. F.			80% L. F.	50% L. F.	30 % L. F.			
Equip. and P.H., Etc.	Other Costs.	Total Costs.	Total Cost.	Total Cost.	Total Cost.	80% L.F.	50% L.F.	30% L.F.
\$80	\$420	\$500	\$520	\$580	\$687	4.0	16.0	37.4
70	430	500	518	570	663	3.6	14.0	32.6
60	440	500	515	560	640	3.0	12.0	28.0
60	340	400	415	460	540	3.8	15.0	35.0
50	350	400	412	450	517	3.0	12.5	29.2
60	240	300	315	360	440	5.0	20.0	46.7
50	250	300	312	350	417	4.0	16.7	39.0
50	200	250	262	300	367	4.8	20.0	46.7
40	210	250	260	290	343	4.0	16.0	37.3
30	70	100	108	130	170	8.0	30.0	70.0
20	40	60	65	80	107	8.3	33.3	77.7

TABLE 5.
FIXED CHARGES FOR HYDROELECTRIC PLANTS WITH VARYING COST OF PLANT
AND LOAD FACTOR.

COST OF PLANT PER H.P.		FIXED CHARGES IN CENTS PER KW. HR. OF OUTPUT AT SWITCHBOARD.			
Total Cost.	Cost of Equipment and P.H.	Load Factor.			
		100%.	80%.	50%.	30%.
\$500	\$80	0.82	0.86	0.95	1.13
500	70	0.82	0.85	0.94	1.09
500	60	0.82	0.85	0.92	1.05
400	60	0.66	0.68	0.76	0.89
400	50	0.66	0.68	0.74	0.85
300	60	0.49	0.52	0.59	0.72
300	50	0.49	0.51	0.58	0.69
250	50	0.41	0.43	0.49	0.60
250	40	0.41	0.43	0.48	0.56
100	30	0.16	0.18	0.21	0.28
60	20	0.10	0.11	0.13	0.18

Cost of Power from Hydroelectric Plants. — Fixed charges on the cost of a water-power development, or the basis for annual cost of power, constitute approximately 10 per cent. of the construction cost, the variation being about as follows:

Interest	5 to 6 per cent.
Depreciation	2 to 3 per cent.
Taxes and insurance	1 to 2 per cent.
Total	8 to 11 per cent.

Assuming annual fixed charges at 10 per cent., the cost per kilowatt-hour for 24-hr. 365-day power has been computed and is given in Table 5, using the range in first cost and load factors as noted previously, and assuming water available to full plant capacity at all times, with no waste.

The fixed charges represent the chief item of cost for hydroelectric power at the switchboard. The remaining items of operating costs will not usually exceed 0.10c. per kw.-hr., being less with large plants and high-load factors and greater with the converse of this situation.

On the other hand, it must be kept in mind that a hydroelectric plant on a typical New England stream, without storage, would not deliver its full output for a considerable portion of the average year, depending on the extent of development. Assuming a development up to a flow available 40 per cent. of the time (and 100 per cent. L. F.), as previously shown in Fig. 7, this would for the average stream afford an output of about 70 per cent. of the wheel capacity, without any allowance for water lost due to leakage or waste. (As further noted, this percentage may be very materially bettered by storage regulation.) To allow for waste it would probably be desirable to assume as the output in an average year only about 60 per cent. of the plant capacity instead of 70 per cent., so that fixed charges as given in Table 5 would be increased in the ratio of $\frac{1}{0.60}$, or 1.67.

Comparison with Cost of Steam Power. — This ratio has been applied to the power costs for certain of the plants assumed in Table 5, adding thereto 0.1c. per kw.-hr. for operating costs, and the results given in Table 6 for comparison with the cost

of steam power, using for the latter (Table 7) data presented by Mr. W. F. Uhl.*

Comparing the lowest-cost water power with that of steam power based on \$3.00 coal, there is a margin in favor of the water power of about 0.3c. to 0.5c. per kw.-hr. With a steam plant costing \$75 per kw. and \$5.00 coal, a cost of water-power plant between about \$250 and \$300 per h.p. results in about the same power cost for both water and steam. The average undeveloped water power in the state of Maine at about \$100 per h.p. would have from 0.4c. to 0.7c. per kw.-hr. advantage over steam power, with \$5.00 coal.

TABLE 6. — COST OF WATER POWER.

Plant Cost.	COST OF WATER POWER AT SWITCHBOARD IN CENTS PER KW.-HR. (A).		
	100% Load Factor.	80% Load Factor.	50% Load Factor.
\$500	1.47	1.52	1.68
400	1.20	1.23	1.37
300	0.92	0.97	1.08
250	0.78	0.82	0.92
100	0.37	0.40	0.45
60	0.27	0.28	0.32

TABLE 7. — COST OF STEAM POWER — (W. F. UHL — 1918).

Cost of Coal. (Ton of 2 000 Lbs.)	COST OF POWER IN CENTS PER KW.-HR. 5 000 KW. PLANT RUNNING 8 760 HRS. YEARLY.					
	50% Load Factor.		80% Load Factor.		100% Load Factor.	
	Plant \$75 per Kw.	Plant \$150 per Kw.	Plant \$75 per Kw.	Plant \$150 per Kw.	Plant \$75 per Kw.	Plant \$150 per Kw.
\$3.00	0.77	0.99	0.58	0.72	0.49	0.62
4.00	0.91	1.13	0.68	0.83	0.60	0.72
5.00	1.04	1.26	0.80	0.94	0.70	0.82
6.00	1.17	1.39	0.90	1.05	0.80	0.93
8.00	1.44	1.66	1.12	1.27	1.01	1.13
10.00	1.71	1.93	1.34	1.49	1.22	1.34
12.00	1.98	2.20	1.56	1.71	1.43	1.54

* Transactions American Society Mechanical Engineers, 1918.

On the basis of 60 per cent. L. F. — which ought to be obtained (and in a large power system may be materially bettered) — water power will cost from about 0.3c. to 1.0c. per kw.-hr., through the range of cost practicable under normal conditions (viz., up to about \$300 per h.p.); steam power will cost a little less than 1c. per kw.-hr. with \$5.00 coal — an average margin of, say, about 0.4c. per kw.-hr. in favor of the water power. What the future cost of coal will be is problematical. If it is not to be less than \$8.00 per ton, as predicted by some, this would mean, for the conditions just assumed, about $1\frac{1}{3}$ c. per kw.-hr. for steam power, which would materially extend the range of feasible cost for water-power developments.

Cost of Transmission. — As most of the remaining attractive water-power sites in New England are situated at a very considerable distance from the present manufacturing centers, to fairly compare the cost of water and steam power, to the former should be added the cost of transmission. This subject was treated by the writer, in collaboration with Prof. Ralph G. Hudson, in his report to the Public Utilities Commission of the State of Maine in 1918, and appended hereto (Table 8) is a tabular extract from that report. As will be noted by reference to these tables, power transmission *in large units*, at a cost of 0.1c. per kw.-hr. or less, is readily obtainable.

Transmission costs would cut the margin in favor of water power for the "average feasible plant" from about 0.4c. down to 0.3c. per kw.-hr., on the basis of approximately normal plant costs, and coal at \$5.00 per ton. With coal at \$8.00 per ton, the margin in favor of water power would be about 0.6c. per kw.-hr. for the "average feasible plant."

Dependability. — A water power depends upon natural agencies for its supply of power, which will in an unregulated stream be variable in amount, and perhaps require an auxiliary steam plant. Storage and pondage will help materially to equalize seasonal and daily fluctuations in water available for power.

Experience of the past few years has shown that steam power may increase greatly in cost and even fail for lack of coal supply, due to labor and transportation difficulties. Our perspective of

TABLE 8.
 ESTIMATED COST OF TRANSMISSION LINES.

Distance. Miles.	Capacity of Line. Kw.	Line Voltage.	Number of Tower Lines.	Number of Wires per Tower.	Total Cost per Mile.
25	5 000	66 000	1	6	\$3 500
25	10 000	66 000	1	6	5 000
25	20 000	66 000	1	6	7 000
50	10 000	66 000	1	6	5 000
50	25 000	66 000	2	6	10 000
50	50 000	100 000	2	6	14 000
75	50 000	100 000	2	6	14 000
75	100 000	150 000	2	6	20 000
100	100 000	150 000	2	6	20 000

ESTIMATED COST OF POWER TRANSMISSION.

Length of Line. Miles.	Capacity of Line. Kw.	Total Capital Cost of Line.	Capital Cost per Kw. Transmitted (50 Per Cent. L. F. and 5 Per Cent. Losses).	Cost per Kw.-Hr. (with Annual Cost 25 Per Cent. of First Cost).
25	5 000	\$87 500	37	\$0.10
25	10 000	125 000	26	0.08
25	20 000	175 000	18	0.05
50	10 000	250 000	53	0.15
50	25 000	500 000	42	0.12
50	50 000	700 000	29	0.08
75	50 000	1 050 000	44	0.13
75	100 000	1 500 000	32	0.09
100	100 000	2 000 000	42	0.12

ANNUAL OPERATING COST OF TRANSMISSION LINES.

(Per cent. of capital invested.)

Interest.....	7 per cent.
Depreciation.....	6 per cent.
Operation, maintenance and taxes.....	12 per cent.
Total.....	25 per cent.

the relative dependability of water and steam power has thus been materially changed, and the value of water power as a standby, even at greater cost than steam, is now better appreciated. In many cases power cost is but a small percentage of cost of product, so that dependable power even at greater cost is well worth while.

STORAGE DEVELOPMENT.

General Statement. — In the foregoing comparison of cost of water power and steam power a typical New England stream has been assumed without storage, which means that a considerable percentage of the time the flow and available power will be low, and in this respect the water-power plant is at a disadvantage with the steam plant. It is for this reason often desirable on streams where little storage exists to have an auxiliary steam plant to supplement the use of water power, with particular reference to a good output of primary power. Where storage is available at reasonable cost the flow of a stream may be more nearly equalized and the amount of primary power materially bettered.

To illustrate this effect, Fig. 8, was prepared for the Saco River at West Buxton, Me., showing the effect of a total storage of 14 billion cu. ft. on the river above this point. The present duration curve for the Saco River with little or no storage is shown by curve No. 1, while, depending upon the method of operating storage, viz., for best primary power, or using the storage yearly, the duration curve will take the form of curve No. 2 or curve No. 3. The basis for this diagram consisted of a hydrograph study for the period 1908-16, and it will be noted that the primary power if taken at the flow available 95 per cent. of time is increased from that corresponding to a flow of about 0.44 sec.-ft. per square mile to about 1.03 sec.-ft. per square mile, or nearly $2\frac{1}{2}$ times. The average output of a plant developed to a flow available 40 per cent. of the time would also be materially better than for the natural stream. In making the studies of the effect of storage in the state of Maine, a mean of curves No. 2 and No. 3 was assumed as the probable actual method of storage

operation, and with this assumption it will be noted that the required plant capacity would be but little different with the regulated flow, but the flow available during the year with

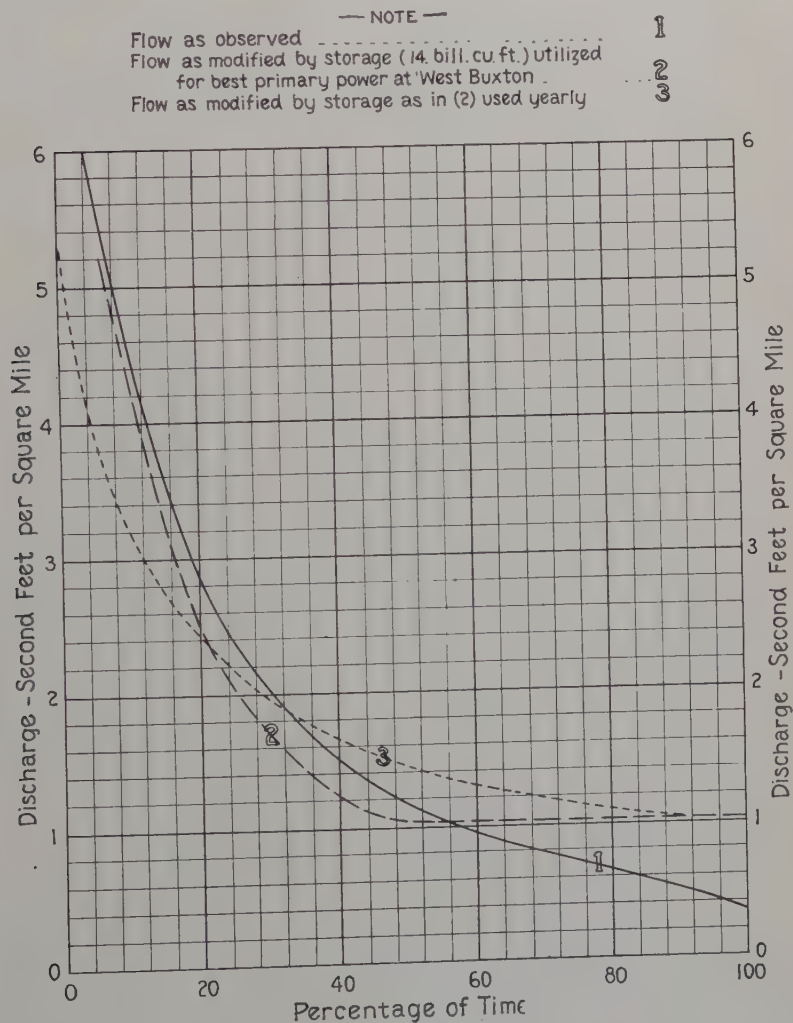


FIG. 8. — SACO RIVER AT WEST BUXTON, ME. FLOW DURATION CURVES, 1908-1916.

storage would be about 84 per cent. of the amount for 40 per cent. flow development instead of only 73 per cent. with the natural flow (curve No. 1).

Cost of Storage.—The allowable cost of storage will evidently vary for a given river with the number of plants or total head at which the stored water can be utilized. A theoretical limit based upon coal saving may be approximated as follows: Of the cost of steam power a little less than a cent per kilowatt-hour, as previously noted, at a good-sized plant, with 60 per cent. load factor, about 0.6 of a cent would consist of coal cost with coal at \$5.00 per ton, or approximately \$52.00 per kilowatt-year. One million cubic feet of storage utilized through a head of 1 ft. would give at the switchboard about $1/450$ of a kilowatt-year, or 11.5c. per year expressed in coal cost. Capitalized at 10 per cent., the annual cost (interest, depreciation, taxes, repairs, etc.) would be about \$1.15, which on this basis could be expended per million cubic feet of storage per foot of fall, provided all of the stored water was utilized. Due often to lack of pondage or control of the water by other plants on the stream the full amount of stored water cannot be utilized. In fact, in many cases this might be as little as one half, or about 56c. per mil. cu. ft. per foot of fall. Taking 50c. as perhaps a limit, it is evident that an available head of 100 ft. would warrant an expenditure of about \$50.00 per mil. cu. ft. of storage, 200 ft., \$100.00 per mil. cu. ft., etc. This would not include any allowance for the cost of operating storage, which however would seldom be over a few cents per million cubic feet annually per foot of fall.

On a river largely controlled by a single interest, like the Deerfield, less stored water would be wasted and a proportionately greater cost of storage development would be warranted.

Cost of Storage Reservoirs.—In the appended table (Table 9) the estimated costs of storage reservoirs for various rivers in the state of Maine are given, which show an average cost of about \$33.00 per mil. cu. ft. For the developed power sites which would utilize these storage reservoirs the cost per million cubic feet per foot of fall would be only about 15c., and including the total available power on these streams the cost would only

TABLE 9.
COST OF INCREASED STORAGE IN MILLION CUBIC FEET PER FOOT OF FALL.

River.	Increased Storage Mil. Cu. Ft.	Total Cost of Increased Storage.	Average (weighted) Head for Storage Use.			COST OF INCREASED STORAGE.			
			At Developed Sites. Ft.	At Un-developed Sites. Ft.	At Both. Ft.	Per Mil. Cu. Ft.	Per M.C.F. per Ft. of Fall.		
							At Developed Sites.	At Un-developed Sites.	At Both.
Presumpscot.....	14 000	\$151 000	250	...	250	\$10.79	\$0.04	...	\$0.04
Union.....	9 150	136 000	78	...	78	14.85	0.19	...	0.19
Kennebec.....	17 060	802 000	185	666	851	47.00	0.25	\$0.07	0.06
Androscoggin*.....	7 550	200 000	427	213	640	53.60	0.13	0.25	0.08
Penobscot.....	22 630	447 000	211	284	495	19.70	0.09	0.07	0.04
Saco*.....	10 720	957 000	202	105	307	95.70	0.47	0.91	0.31
Total or Weighted Average.....	81 110	\$2 693 000	216	253	469	\$33.20	\$0.153	\$0.131	\$0.071

* In the state of Maine only.

be about 7c. per mil. cu. ft. per foot of fall. Conditions in the state of Maine are thus extremely favorable for storage development, and in fact many of the rivers even now have sufficient storage capacity available to materially equalize their flow.

Some data of actual and estimated cost of storage reservoirs in New England and New York are given in the following tables:

COST OF STORAGE RESERVOIRS.

Reservoir.	Purpose of Storage.	Cost.	Capacity. Mil. Cu. Ft.	Cost Per Mil. Cu. Ft..
<i>Constructed.</i>				
Aziscohos, Me.....	Power	\$1 000 000	9 600	\$105
Ripogenus, Me.....	do.	1,000 000	25 000	40
Somerset, Deerfield R., Vt...	do.	800 000	2 675	299
Indian River, N. Y.....	do.	83 555	4 460	19
Wachusett, Mass.....	Water supply	11 021 353	8 760	1 260
Ashokan, N. Y.....	do.	12 699 775	16 030	792
<i>Estimated.</i>				
Portage, Genesee R., N. Y...	Power	4 520 000	11 250	402
Scandaga, N. Y.....	do.	4 500 000	29 000	155
Oxbow, Raquette, N. Y.....	do.	1 745 000	15 000	116
Saranac Lake, N. Y.....	do.	614 000	4 000	154
Harrisville, Oswegatchie, N. Y.....	do.	696 000	5 000	139
Black Lake, N. Y.....	do.	580 000	6 000	97
Eel Weir Rapids, N. Y.....	do.	150 500	11 000	14

ESTIMATED COST OF PROPOSED HIRAM RESERVOIR ON SACO RIVER.

Total storage capacity = 10 000 mill. cu. ft.

Item.	Estimated Cost.	Per Cent. of Total Cost.	Cost per Mil. Cu. Ft.
Construction cost.....	\$329 000	34	\$32.90
Land, flowage, etc.....	440 000	46	44.00
R. R., roads and bridges, etc.....	188 000	20	18.80
Total.....	\$957 000	100	\$95.70

ESTIMATED COST OF PROPOSED STORAGE RESERVOIRS ON WOOD, ATTEAN
AND BRASSUA LAKES.

Total storage capacity = 7 340 mil. cu. ft.

Item.	Estimated Cost.	Per Cent. of Total Cost.	Cost Per Mil. Cu. Ft.
Dams, bridges, etc.....	\$290 000	88	\$39.50
Land.....	40 000	12	5.50
Total.....	\$330 000	100	\$45.00

Results from Storage Reservoirs. — One of the most interesting of the reservoirs listed above is the Somerset Reservoir, on the Deerfield River, built in 1912 at a cost of about \$300 per mil. cu. ft., the water from which is now being utilized by the New England Power Company through a total developed head of 500 ft., and will, with future possible developments, be available for a total head of over 1 600 ft. The effect of the Somerset Reservoir on the flow of the Deerfield is shown on Fig. 9 in the comparative duration curves at Charlemont, in one case corrected for storage and in the other as observed, including the effect of this storage. On this chart is also shown the natural flow into the Somerset Reservoir, as well as the flow actually released from it. During the five-year period October, 1913, to September, 1919, inclusive, the average amount of water actually released from this reservoir annually has been about 75 per cent. of its capacity.

Possibilities of Storage Development in New England. — Additional storage possibilities in the state of Maine, as appended, aggregate on the principal rivers a total amount of about 81 bil. cu. ft. Considerable opportunity also exists for storage development in the other New England states, although usually at considerably greater cost than in Maine.

In *New Hampshire*, on the Connecticut and its tributaries, there is at present about 9.5 bil. cu. ft. of storage, with about 15 bil. not yet developed. On the Merrimack River and tributaries

about 22 bil. cu. ft. of storage can also be developed, or a total for these two rivers in the state of about 37 bil. cu. ft.* The estimated average cost of 21 of these storage reservoirs on the

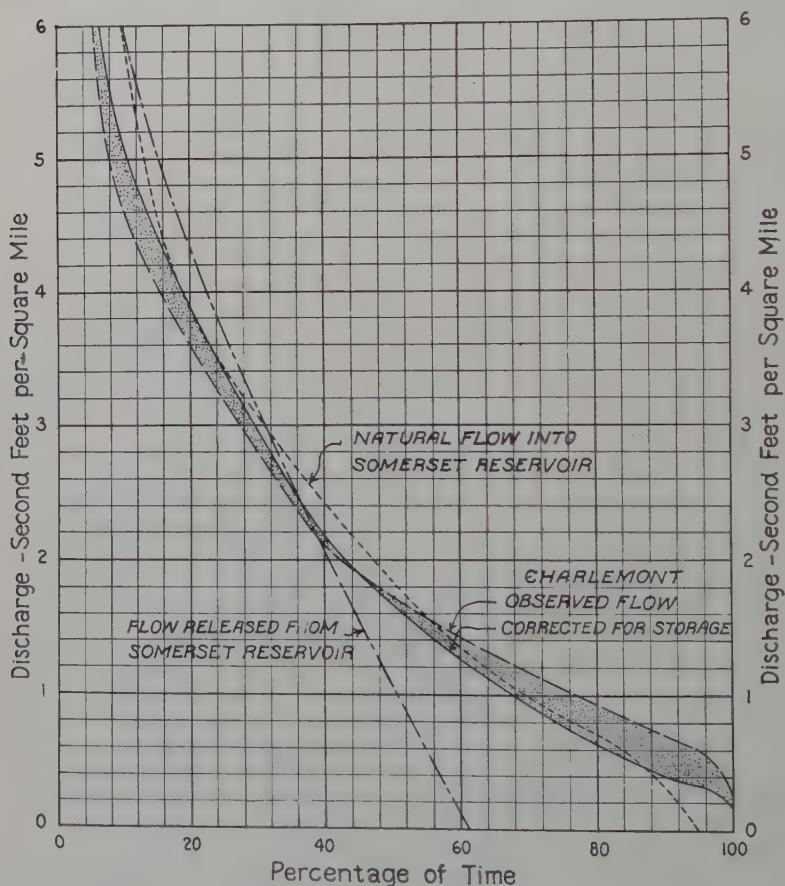


FIG. 9. — DEERFIELD RIVER AT CHARLEMONT, FLOW DURATION CURVES, 1913-14 — 1918-19.

Contoocook River and tributaries, where a total storage capacity of about 9.5 bil. cu. ft. can be obtained, is about \$148 per mil. cu. ft. The total coal saving, based on 3 lbs. of coal per kilowatt-

* New Hampshire W. P. Report, 1918.

hour and 80 per cent. efficiency of power plant for the total amount of available storage on the Connecticut and Merrimack and tributaries, is estimated at about 278 000 tons per year, of which about 105 000 tons would be at plants outside of New Hampshire.

In *Vermont* the report of the Vermont Conservation Commission in 1917 shows that nearly 10 bil. cu. ft. of storage can be developed on tributaries of the Connecticut River, Otter Creek and Winooski River, without, however, any data of cost of this development.

In *Massachusetts* the Waterways Commission in 1918 reported that additional storage of about 21.5 bil. cu. ft. could be obtained, the greater portion of it being on tributaries of the Connecticut River and on the Nashua River, but not including the Deerfield River. Data of cost are given for the proposed reservoirs on Millers River, which aggregate about 6.4 bil. cu. ft. and were estimated to have an average cost of \$354 per mil. cu. ft. usable through a total head of somewhat over 300 ft. Conditions are not as favorable for storage development in Massachusetts, with the exception of the Deerfield River, as in the northern states. No data are available for *Connecticut* or *Rhode Island*.

Difficulties of Storage Projects. — Where a storage reservoir is located on a stream with many different owners of water power, it is often difficult to get all to contribute toward the cost of the storage development and its maintenance and operation. In the case of the Deerfield River, as already noted, nearly the entire stream is controlled by one company and the total amount of fall is so great that storage is both practicable and desirable. In the case of the Androscoggin River in Maine, largely through the efforts of Mr. Walter H. Sawyer, C. E., the Azischohos Reservoir on the Magalloway River, in the headwaters of the Androscoggin, was built in 1911, affording a storage capacity of about 9.5 bil. cu. ft. of water. This was financed by the four large users of power on the river, viz., the Union Water Power Company, the Berlin Mills Company, the International Paper Company, and the Rumford Falls Power Company, by agreement whereby each company purchased stock in the Azischohos

Reservoir Company equal to one fourth of the expense of organization and of construction of the new dam. These companies also participate in the use and cost of stored water from the Rangeley Lake system, and the result of all this storage has been a great improvement in the flow of the Androscoggin, it now being possible to maintain not less than 1 550 cu. ft. per second at Berlin, N. H. (or 1.15 sec.-ft. per sq. mi.). The actual operation of this storage since the construction of the Aziscohos Reservoir has shown somewhat better results than this amount. It will be noted, however, that this storage project has been possible because four large coöperating companies control a sufficient amount of power on the river to make the storage worth while.

Under the Mill Act here in New England, which is essentially the same in the different states, the supreme courts have frequently decided that the erection of a mill dam for the purpose of creating water power for manufacturing and industrial purposes is of public use and benefit and that the owners of such a dam may be given the right to flow land above the dam upon payment of proper damages therefor. It is not at all clear that the scope of this act extends and covers storage reservoirs, even though they be for the purpose of improving the flow of the river and therefore water power use. The lack of a legal basis whereby land and flowage rights may be taken in order to construct storage developments and the further lack of authority to collect tolls, or the cost of storage improvement and its operation, from owners along a stream, are two of the most serious obstacles which at present are retarding storage developments here in New England, as well as in many other portions of the country.

REDEVELOPMENT OF WATER POWER.

Many of our water-power developments in New England date back to the middle of the past century, and even earlier. They are consequently in many cases laid out so as to utilize only partly the entire amount of available power. This has often been due to the manner in which in the olden days a good fall was divided into a number of smaller falls, with the

consequent duplication of leakage, canal and tailrace losses, etc. There are many cases where it would be feasible, and in fact a good return could be obtained upon the investment, to make a redevelopment along modern lines.

The water-power development at Holyoke is a good example of the older type of development in several falls, with a large space occupied by canals. From an engineering point of view this could readily be redeveloped in one fall, with a substantial saving in power. The various long-time leases of power, however, held by many different mills represent a serious difficulty in any such redevelopment. There are, however, several of these older developments in New England which sooner or later, as land and power costs increase, may be redeveloped.

At Bellows Falls on the Connecticut River is an old development where there is a large amount of leakage and waste of power. The New England Power Company, which now control this privilege, have in mind a redevelopment which will add very considerably to the power output from this site.

Another site which could be redeveloped and show a much greater power output is Penacook, N. H., on the Contoocook River, where a fall of about 100 ft. can readily be developed, replacing several poorly developed and wasteful plants now located at this point.

Another important feature of improvement is the installation of modern turbines. Progress during the last decade in improving water wheels has been marked, and actual tests of wheels showing as high as 93 per cent. efficiency are not uncommon. Under reasonably good conditions working efficiencies of 85 per cent. or even better can be obtained, which is probably 15 to 20 per cent. better than that of the average New England plant with old wheels. Where power is in demand any increase in wheel efficiency means practically a proportionate increase in income or earning power of the plant. The importance therefore of adding 15 to 20 per cent. to output is obvious.

The two methods of increasing available water power by improving the plant layout and installing modern wheels are of sufficient importance to warrant a careful investigation and report on this subject, as has been done in respect to the development of power sites by several states.

THE FUTURE OF WATER-POWER DEVELOPMENT IN NEW ENGLAND.

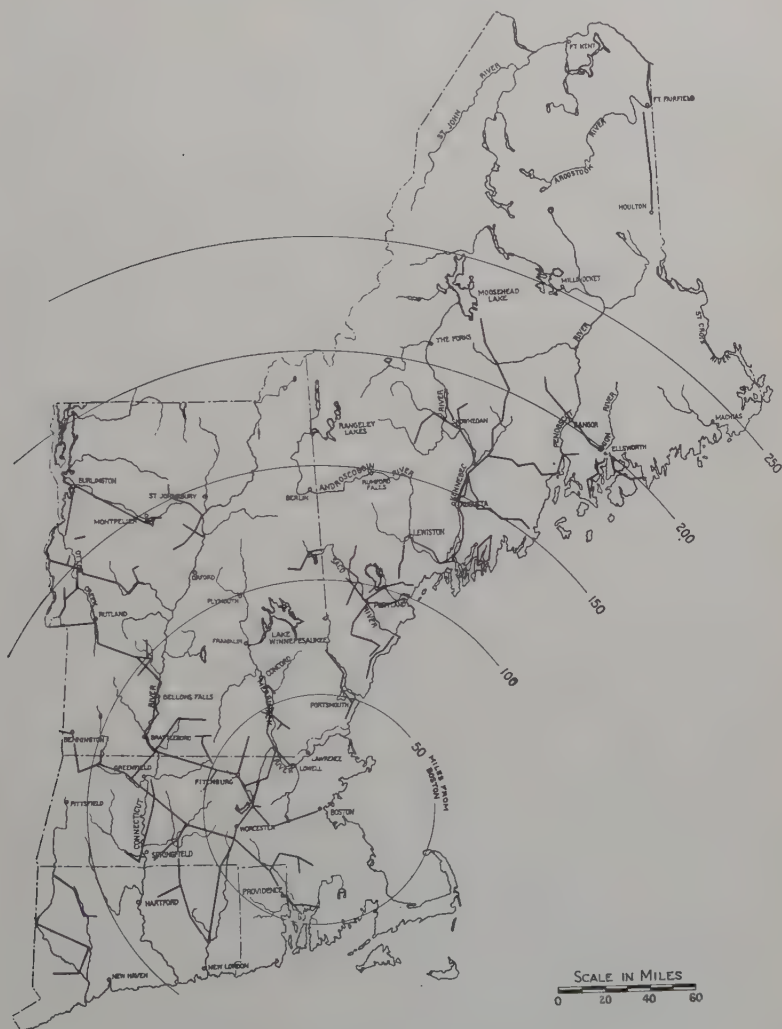
Lower Costs. — The figures presented of the amount of water power as compared with total power requirements show clearly that our total power needs would consume all the available water power in New England at the present time, provided this was feasible commercially and from the point of view of transmission of power. The figures presented do not include the amount of power used by locomotives, which is already a field invaded by water power, — notably in the West.

The extent to which the cost of coal has increased, as well as the great difficulty in obtaining it in many cases, even at prohibitively high cost, point unmistakably to the need of a comprehensive water-power development for New England, taken as a whole. Keeping in mind dependability as previously noted, water-power costs, particularly on streams where storage can be made available, will be justifiable, even though somewhat in excess of the cost of steam power.

Construction costs for the last two years or more have been prohibitive of all but emergency work, and only a small amount of water-power construction has been going on during this time. There is, however, indication of a break in costs of materials and labor at the present time, and it is reasonable to suppose that perhaps in the near future construction of some of the necessary power projects may be started.

Transmission of Water Power beyond State Lines. — As has been noted, the greater portion of the undeveloped water power in New England lies in the state of Maine. At the present time a state law prevents the transmission of this power outside the state boundary. On Fig. 10 is a map of New England showing the main transmission lines, with particular reference to use of water power; also distances in an air line from Boston. It will be noted that the greater part of the undeveloped water power in both the states of Maine and New Hampshire is within possible transmission of eastern Massachusetts, where of course large amounts of power could be utilized.

The extent to which state lines should interfere with the free use of a natural resource like water power is a broad question,



and one in regard to which public opinion has probably changed somewhat during the eleven years that this Maine law has been in operation. The theory underlying this law was said to be that industries would be attracted to the state by the cheap

water power. This tendency has, however, apparently been offset by transportation difficulties. Would it not be wiser for the state of Maine to permit the leasing of a portion of its surplus undeveloped water power over a sufficient term of years to make this worth while to an investor, allowing it to be transmitted to the great power market in southern New England? As an illustration of what this might mean, 100 000 kw. of power from the Kennebec River and its general vicinity could be transmitted to eastern Massachusetts at low cost per kilowatt-hour and tied in with the comprehensive power system of the New England Power Company and other companies.

A low rental charge per kilowatt-year might be required for such power going from the state. This rental, together with the increased amount of taxable property, would afford a source of revenue to the state where at present practically no return is obtained. The lease should include proper provision with respect to use of power within the state when this becomes necessary in the future. There would also be a distinct advantage in a continuous transmission line between the states of Massachusetts and Maine, for such a line and its connections would have a greatly diversified field of supply of both steam and water power, and more favorable operating conditions and a better output would result.

The same general situation is true with reference to New Hampshire, which has a considerable amount of undeveloped power not usable at the present time. In fact, taking New England as a whole, the ideal situation from the point of view of power would be to forget state lines and look upon it as a single area or unit. It is not so large in area but that interconnected main transmission lines could readily reach all except perhaps northern Maine.

Storage.—The difficulties in the way of development of storage have already been outlined. In Wisconsin, a river regulation act for the Wisconsin River was passed in 1907, and a company has built and is operating storage reservoirs on this stream, assessing tolls upon the various power owners. In this case, however, it was brought about by the unanimous consent of parties in interest, power of eminent domain in acquiring the

land and water rights being given, based largely upon public use or benefit due to effect upon navigation.

New York has quite an elaborate act, passed in 1916, creating storage reservoir districts as municipal corporations with power of eminent domain, and collecting the contributions from down-stream owners in the form of taxes. Under this act the regulating district on Black River has been formed. No reservoirs have yet been built, however, nor has the law been tested in any court decision.

Here in Massachusetts several attempts have been made to procure legislation giving right of eminent domain in storage projects and in assessing tolls upon owners along the stream. As yet, however, no definite action has been taken by the legislature in adopting such an act. Legislation on this matter is also under consideration in several other states.

Public opinion seems to be shaping itself toward measures by the states whereby water storage may be effectively planned, carried out and operated under some form of state supervision (and possibly in some cases with the aid of the state). Comprehensive and workable legislation along this line is one of the most important needs to effect a more complete water-power development here in New England.

Federal Water-Power Commission. — The scope of the work of the Federal Water-Power Commission which was established by Congress at its last session is based fundamentally upon the improvement of navigation, navigable waters being defined as "those over which Congress has jurisdiction under its authority to regulate commerce with foreign nations and among the several States," this referring to rivers in either their natural or improved condition and (notwithstanding interruptions by falls or rapids) which are used, or are suitable, in interstate or foreign commerce. Just how far the scope of this commission's work will affect our New England streams is not clear. A stream like the Connecticut River, for example, is navigable in its lower portions and is an interstate stream. Technically, storage projects on the upper main river, as well as on any tributary, affect this navigability, and in fact there are few of the larger streams in New England which are not navigable to some extent as defined by this act.

Provision is made in the Federal Water-Power bill whereby the right of eminent domain can be invoked in storage projects and in assessing tolls. The extent to which this may apply in New England, however (except perhaps in such cases as Windsor Locks, on the navigable portion of the Connecticut River), is questionable, as much will depend upon the breadth of interpretation of the control of navigable waters assumed by the Federal Power Commission and developed by court decisions.

Concluding. — To summarize the situation briefly:

1. New England has about 2 million h.p. of water power, a little over half of which is developed.
2. Over half of the undeveloped water power is in the state of Maine, and about one fourth in New Hampshire. Only about one sixth is in southern New England.
3. A portion of this undeveloped water power is too expensive — even with costs again somewhere near the normal — to warrant development. Much of it would be worth while developing, in view of a probable permanent increase to some extent in cost of coal, over the old normal figures, provided a market for power was at hand.
4. The great power demand is in the southern three states — particularly Massachusetts, which could absorb much of the water power from the northern states if available.
5. A state law in Maine now prevents the transmission of water power beyond the state lines, and therefore the early use of a large part of the best undeveloped water power in New England.
6. The amount, reliability and value of water power can in many cases be greatly increased by storage developments. At present these are in most cases impossible because of lack of power to take land and water rights, as well as to distribute the construction and operating costs equitably.
7. The best use of the water-power resources of New England would be possible by disregarding state lines or looking at the six states as a unit. A comprehensive power transmission system could then practically interconnect the greater part of New England, with great resultant advantage in dependability of power, better load factors and power output.

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PAPERS AND DISCUSSIONS

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THE ST. LAWRENCE RIVER PROJECT.

BY HENRY I. HARRIMAN.*

(Presented December 17, 1920.)

IN my capacity as a member of the Massachusetts Commission on Foreign and Domestic Commerce, my attention has been called in the last few months to a proposal which has come from the West, relative to the opening of the St. Lawrence River to navigation. As you know, the Great Lakes span about one thousand miles in the heart of North America. It is one thousand miles from Duluth to Buffalo, and in that region reside about 40 per cent. of the total population of the United States. It is a region rich in agriculture, rich in minerals and thickly populated. Ninety per cent. of our iron ore comes from the shores of the largest of the Great Lakes, — Lake Superior; much of our copper, coal, wheat and other grains come from this fertile region, and some of our greatest manufacturing cities are found there. In the last thirty years there has grown up on those lakes a commerce greater than the combined commerce of the Mediterranean and the Black seas. More vessels pass through the locks between Lake Superior and Lake Huron than pass through the Suez and Panama canals combined. This great traffic of the lakes moves eastward until it comes to Buffalo, and from that point it must be transferred to trains and finish the journey to the seaboard by rail. This causes a breaking of bulk at Buffalo, and means a more expensive form of transportation, so it is no

* 50 Congress Street, Boston, Mass.

wonder that the West, attempting this tremendous traffic and commerce and tremendous agricultural and manufacturing intercourse, is asking that the sea be opened to the Great Lakes.

There are two natural obstacles that lie between the eastern end of Lake Erie and sea level in the St. Lawrence. One is Niagara Falls and the other the rapids of the St. Lawrence River. There has been a shallow canal for many years around both of these obstacles, but it was so small that it really served little commercial purpose. About two years before the outbreak of the war a crusade was started to build the new Welland Canal around Niagara Falls. That is nearly completed — probably it will be finished within four or five years — and will make it possible for boats drawing 22 to 26 ft. of water to pass from Lake Erie to Lake Ontario. There will then be but one obstacle, — that is, the rapids of the St. Lawrence River. And now from the West, from 15 western states officially represented, there has come the demand to Congress that this river be made navigable, in order that the traffic of the lakes may get directly to the ocean, and they are waging a very active campaign. I am not here to discuss the problem from the standpoint of the West, they are fully capable of presenting their own needs, but it seems to me that the project promises much to New England.

At first blush it seemed that it might be a detriment to our section of the country, because of the possible ill effect upon foreign commerce, but more complete study has convinced me that it has even greater promise for the East than for the West. If the St. Lawrence River is canalized it will be by the construction of a series of dams across the river, — possibly a dam and a canal in some sections, — but in any event much of the river will be dammed, and that means it will be possible to develop at the ends of these dams created for navigation purposes very great power plants and make available for the United States, for Canada and New York State a really unthinkable amount of power. The flow of the St. Lawrence River has been carefully gaged for over sixty years, and is given on the best authority at about 241 000 sec.-ft. The flow is extremely uniform, because the Great Lakes serve as a huge equalizing reservoir. The minimum and maximum flows vary less than 25 per cent. from

the mean, and if certain projects which engineers have suggested are carried out for the creating of a dam on the Niagara River, which will raise the level of Lake Erie about 3 or 4 ft., this will still further equalize the flow of the St. Lawrence and make the variation not over 10 per cent. So the flow is perhaps the most uniform of any large river in the world. The St. Lawrence River drains one fourth of North America, and in its course falls 221 ft. In the 113 miles along the international boundary the fall is 91 ft., and in the 70 miles of rapids above Montreal there is an additional fall of 130 ft. It is proposed that the entire river be developed for the joint use of the two nations. While Canada will not of course be able to entirely alienate any portion of the power within her boundaries, she has consented to make long-time leases for export of power from that section of the river which she owns. From the international section our country will be entitled to one half of the power. Engineers estimate, and I think conservatively, that if the St. Lawrence is canalized and the power developed, it will be possible to generate 4 million h.p. from the river, and that is equivalent to the energy which could be produced from 24 million tons of coal burned in the most modern and efficient steam plant, or of 36 million tons burned under the boilers of an average New England mill. So that gives you the tremendous possibility that there is for power in this river. That power translated into kilowatts per hour means that the St. Lawrence River is capable of developing about 26 billion kw.-hr., which can be transmitted from the St. Lawrence River and delivered at substations in New England, Canada and New York State. If we assume that by direct ownership and treaty right America has the privilege of using half of that power, we would have at least 13 billion kw.; and if New England gets behind that project, as it should, it should have half America's share. Of necessity, the market of this power is limited to New England, New York, Canada and possibly a small section of New Jersey. Thus far it has not been found feasible to transmit power over 300 miles, and the 300-mile circuit passes just outside of Boston. It takes in a portion of New England, the entire state of New York, half of New Jersey and a little section of Pennsylvania. So we are in a natural geographical position to

use at least half of the portion of the power which America should be entitled to, — one quarter of the whole. We should be able to have here, when the power is completely developed, about 6 billion kw.-hr.

I should like very briefly to discuss with you what the power requirements of New England are. The utilities of New England to-day are generating about 2 billion kw.-hr., but it is fair to assume that fully one fourth of that power now comes from water, and therefore we may assume, for the sake of argument, that the utilities can use about $1\frac{1}{2}$ billions of this St. Lawrence power. The railroads should be and will be electrified in the near future, and there are 5 000 miles of railroads in New England. But 1 500 miles of railroad transport 80 per cent. of the tonnage of New England railroads, and so it is only necessary to electrify about 1 500 miles of road in order to handle the great bulk of the railroad tonnage of this section. For instance, the Fitchburg Division of the Boston & Maine handles nearly 40 per cent. of that system's total tonnage. The railroads of New England are using about 6 million tons of coal a year, and if 80 per cent. could be replaced by electric power, it would be true that electricity was replacing about 5 million tons of coal. That coal last year cost New England railroads nearly 50 million dollars. If they had bought St. Lawrence River power at 1c. per kw. the cost of energy represented by 5 million tons of coal would have been about 18 million dollars, — a saving of nearly 30 million dollars, — and a few years' saving would have paid for the electrification of those 1 500 miles of road, including the purchase of the locomotives, track structure and substations. If that saving had been effected it would have been equal to 3 per cent. on all of the outstanding bonds and stocks of all the New England railroads. So you see the tremendous possibility in the electrification of our railroads. The problem is not as complicated as it might at the first blush appear, because a great percentage of the tonnage is hauled over a small percentage of the rails. There are many pieces of track that will probably never be electrified, but those 1 500 miles that bear heavy traffic will, in my opinion, be electrified; and, when they are, the St. Lawrence River can be assumed to supply a sufficient energy to operate

them. That would take another 2 billion kw. So the railways, electric light companies, trolleys, etc., would out of 6 billion kw.-hrs. take about $3\frac{1}{2}$ billion. That leaves a balance of $2\frac{1}{2}$ billion for industry. Let's see what the demands of New England industries are. I have absolutely no authentic information on that. The number of spindles in New England cotton mills is approximately 18 500 000, — 22 spindles per h.p. being a fair allowance. The number of spindles in the woolen mills is 2 199 999, with 4 200 cards, probably requiring about 200 000 h.p. The cotton mills now use about one billion kilowatt-hours, and about 25 per cent. of this now comes from water. The woolen mills require not over 175 000 000 kw.-hrs. Without going into the details of the other industries, like paper, brass, rubber and machine shops, I think it is fair to say that 2 billion kw.-hrs. would be all the power generated by water that New England industries now require, and therefore the St. Lawrence power would be sufficient to supply our railroads and utilities and industries and still leave us one-half billion kilowatts to draw on, and when I say St. Lawrence power I mean merely one quarter of the power, which I believe, from the geographical situation, New England is entitled to.

Now, a word as to the cost of power. A commission of engineers representing both governments is making a careful study of the situation. The best information we have to-day is that the dams themselves, and the locks, but not including the power houses — that portion having directly to do with navigation — will cost 300 million dollars, and if that figure is correct, one mill per kw.-hr. will equal the interest charge, and will also create a sinking fund which will return to the two governments their expenditures, within thirty-five years. I don't know how much the power houses and power plants are going to cost, but we all know that a development of that size, with the heads involved, are cheap developments to build, and I believe it is fair to say that the power can be transmitted and delivered wholesale in the New England states at materially less than 1c. per kw.-hr. — how much less I don't want to prophesy, though probably materially less. And when you consider what it means for New England industries to be freed from the bugaboo of coal, and at

an expense not more than that of \$3 or \$4 coal, I think you will agree that the St. Lawrence development has advantages. I am not quite so optimistic as Professor Barrows in his assumption that we shall return to \$5 coal. I believe New England is going to pay from \$7 to \$9 for its coal in the future. The present freight rate is substantially \$5, and I see nothing in sight to indicate a lower freight rate by rail, though there may be somewhat lower water rates in the future, and I don't believe we shall get a better price than \$7 to \$8 in this region, and if that is so the St. Lawrence power means a great deal to the industry and the people of the New England states.

So much for the power possibilities of the project. I am only going to touch on two other considerations. First, its effect on our domestic commerce, and second, its effect upon our foreign commerce. We are a great manufacturing section. We import from other states large supplies of raw materials, convert them to finished products and ship them to other sections of the world. We import most of our foodstuffs. Six million tons of food products come into these same New England states, for domestic consumption, each year; four million tons of raw materials, also. There is a tremendous domestic commerce that now moves in and out of New England solely by rail.

By rule of thumb it was always said that you could move a ton of material 5 miles by water for the same price that you could move it 1 mile by rail. That ratio was upset during the war, because of the ravages of the submarine, but water rates are rapidly falling and rail rates are increasing, and shippers say to-day that the old ratio of 5 to 1 as between water and rail now holds good. From Buffalo to Boston by rail is 500 miles. The distance via the St. Lawrence, through Lake Ontario and around Niagara Falls, is 1 400 miles, — a ratio of 3 to 1; and I submit that if 5 to 1 is the ratio between the water and rail rates, 3 to 1 means a less cost by water. The ratio between water and rail in Chicago is a little over 2 to 1. That opening of the St. Lawrence will mean boat lines from the ocean shores to the Great Lakes; it will bring in foreign stuff and send out manufactured articles less than is done now by rail. The objection has been raised that the railroads will lose. In answer, traffic is doubling every

fifteen years. It will be at least ten years before this project is finished. It will be the heavy materials that will be taken from the railroads and put on the boats, and instead of a detriment to the railroads it will be a help to them. President Smith of the New York Central believes it will save them millions and millions of dollars in investment in terminals and tracks, if the bulk of the heavy traffic, which pays relatively poorly, is taken from the railroads and they are left to carry that class of material which pays them a better rate.

As to our foreign commerce, there are some of you who feel that much of the traffic which now moves through eastern points will go directly by boat from the lakes to Europe. That may be true. But, even if it is true, I believe that the advantages of the project far outweigh any disadvantages.

The project has the backing of men like Mr. Hoover, Ex-Secretary Lane, — men from various sections of the country, who have studied it and who believe it will not work any lasting harm to any of our eastern points. Of course Buffalo will object to losing the transfer charge which she now has. Naturally, New York State, after building the Erie Canal, will feel that some of the burden will be taken from the canal to the river. New York and Buffalo may lose a little; but isn't the situation about the same as that one hundred years ago, when the power loom was invented and when the weavers in Lancashire destroyed the first mill that had power looms in it? And that power loom has made Manchester the greatest manufacturing center in the world. So sometimes things which seem to be detrimental often work out to our good, and I believe that whatever is a real benefit to the whole country will benefit our foreign commerce. Therefore, if I may sum up the situation, it seems to me that the project offers the solution of our fuel problem. In the first place, it offers us cheaper freight on food and raw materials and manufactured materials, and in the second place possible damage to our foreign commerce will far more than be outweighed by increase in prosperity of our section, through the benefits that will come in the other two ways.

MEMOIR OF DECEASED MEMBER.**LOAMMI FRANKLIN BALDWIN.***

LOAMMI FRANKLIN BALDWIN was born in Naples, Ill., November 6, 1849. He was the son of Loammi 3d and Helen Avery Baldwin, and descended from a distinguished line of ancestors. He was grandson of Major Benjamin Franklin Baldwin, and great grandson of Col. Loammi Baldwin, the eminent engineer and public-spirited citizen who was active in the projection and construction of the Middlesex Canal extending from Lowell to Boston, and in 1826 made an examination and report to the Massachusetts legislature of a system of inland waterways across the state from Boston to the Connecticut and Hudson rivers. Colonel Baldwin was interested in the study of the native fruit-bearing trees and discovered and improved by propagation the Baldwin apple, which was named for him. He commanded the 26th Regiment of Continental troops in the war of the American Revolution. Mr. Baldwin was also a nephew of James Fowle Baldwin, the first president of the Boston Society of Civil Engineers. He was educated in the public schools of Lawrence, Mass., and at Immanuel Hall, Chicago.

In the year 1869 he was employed as rodman on the Champaign and Decatur Railroad in Illinois, and later was rodman on the construction of the Connecticut River Railroad between Hartford and Saybrook, Conn. In 1870 he attended the Massachusetts Institute of Technology, taking the civil engineering course, and left at the end of his third year. In 1873 he became a member of the firm of Coolidge & Baldwin, engaged in general engineering in Lawrence, Mass., and served as assistant engineer on the construction of the Lawrence Water Works until its completion. In 1877 he entered the employ of the Essex Company, and was engaged in hydraulic construction mill work and chimney designs. From 1880 to 1884 he was engaged on geological survey work as principal assistant to James E. Mills, a

* Memoir prepared by Richard A. Hale and James R. Baldwin.

prominent mining engineer, at Mine La Motte, Mo., and Plumas County, Calif., preparatory to placer gold mining there. In 1885 he was chief engineer for the Mohawk Valley Lumber Company, running a preliminary line for their railroad from Long Valley over Beckwith Pass to Sierra Valley in Nevada and California.

Returning east in 1886 he was engaged in construction of mills and hydraulic structures for the late Hon. William A. Russell, who had large paper mill interests in Bellows Falls, Vt., and Mt. Tom and Lawrence, Mass. In 1891 he entered the inspection department of the Associated Factory Mutual Fire Insurance Companies of Boston as engineer and special inspector, remaining with them until his retirement from business on account of ill health in 1915.

In 1873 he married Kate W. Richardson, of Peabody, Mass., who survives him together with two daughters, Miss Clara and Miss Mary, and a son, James Rumford Baldwin, who is a civil engineer with the Essex Company.

Mr. Baldwin was a member of the Boston Society of Civil Engineers, Massachusetts Institute of Technology Alumni Association, Rumford Historical Association, Sons of the American Revolution, National Historical Society and the Woburn Phalanx Association.

He resided in the old Baldwin House in Woburn, built in 1661, which has been changed but slightly from the original construction, and is a noted historic landmark in Woburn, near the statue erected in memory of Col. Loammi Baldwin.

He attended the Episcopal Church, and while in Lawrence took an active part in Grace Church affairs, and was a warm and intimate friend of Bishop Lawrence, who was rector in Lawrence at that time. A large map of the Holy Land painted on the walls of the Parish House was the work of Mr. Baldwin, and has been used in Sunday-school work since that time. He died May 10, 1920, after a long illness.



ADVERTISEMENTS

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INDEX TO ADVERTISERS.

	PAGE
A. B. SEE ELECTRIC ELEVATORS, 111 Devonshire St., Boston.....	VI
ABERTHAW CONSTRUCTION Co., 27 School St., Boston.....	XIV
ADAMS, H. S., 108 Ames Building, Boston, Mass.....	V
ASPINWALL & LINCOLN, 3 Hamilton Pl., Boston.....	V
ASSOCIATED ARCHITECTS PRINTING & SUPPLY Co., 21-27 Pearl St., Boston.....	XIV
BAY STATE DREDGING AND CONTRACTING Co., 62 Condor St., East Boston.....	XVIII
BEATTIE, ROY H., 10 Purchase St., Fall River.....	XIII
BETHLEHEM STEEL BRIDGE CORPORATION, Bethlehem, Pa.....	XVI
BISHOP, J. W., & Co., 683 Atlantic Ave., Boston.....	VI
BLAIR, ISAAC, & Co., INC., 433 Harrison Ave., Boston.....	IV
COLEMAN BROS., 1 Marginal St., Chelsea.....	XIII
CONANT MACHINE Co., Concord Junction, Mass.....	XIII
DONOGHUE, P. W., 170 Purchase St., Boston.....	XV
EASTERN BRIDGE AND STRUCTURAL Co., Worcester.....	XI
FAY, SPOFFORD & THORNDIKE, 15 Beacon St., Boston.....	V
FORT HILL PRESS, 176 High St., Boston.....	XIV
FULLER, GEORGE W., 170 Broadway, New York.....	V
GOW, CHARLES R. Co., THE, 166 Devonshire St., Boston.....	XII
HALL, JOHN G., & Co., 114 State St., Boston..	XIII
HOLBROOK, CABOT & ROLLINS CORPN., 6 Beacon St., Boston.....	VIII
HOLZER, U., 25 Bromfield St., Boston.....	IX
HUGHES, EDWARD F., 8 Oliver St., Boston.....	XIII
KEARNS Co., W. F.....	XIX
LEDDER & PROBST, 21-25 Pearl St., Boston.....	XIII
LEY & Co., INC., FRED T., Springfield, Mass.....	III
MAIN, CHARLES T., 201 Devonshire St., Boston.....	IV
METCALF & EDDY, 14 Beacon St., Boston.....	V
NEW ENGLAND FOUNDATION Co., INC., 70 Kilby St., Boston.....	XIII
NEW ENGLAND SAND & GRAVEL Co., 161 Devonshire St., Boston..	IX
OLD CORNER BOOK STORE, 27 Bromfield St., Boston.....	XIII
PALMER, JOHN E., 1012 Old South Bldg., Boston.....	XIII
PENN METAL Co., 65 Franklin St., Boston.....	VI
PENNSYLVANIA CEMENT Co., 161 Devonshire St., Boston.....	XII
PERRIN, SEAMANS & Co., 57 Oliver St., Boston.....	IX



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	PAGE
RAYMOND CONCRETE PILE CO., 80 Boylston St., Boston.....	XVII
RIDEOUT, CHANDLER & JOYCE, 178 High St., Boston.....	XIII
ROCKPORT GRANITE CO., Rockport, Mass.....	VII
SIMPSON BROS. CORPN., 166 Devonshire St., Boston.....	VII
SMITH, B. F., & Co., Merchants Bank Building 30 State St., Boston	XIII
STONE & WEBSTER, 147 Milk St., Boston.....	X
STUART, T., & SON CO., Newton, Mass.....	XVIII
THOMPSON, SANFORD E., 136 Federal St., Boston.....	V
THORPE, LEWIS D., 201 Devonshire St., Boston.....	V
TUCKER, EDWARD A., Co., 101 Milk St., Boston.....	VII
TURNER CONSTRUCTION COMPANY, 178 Tremont St., Boston.....	XV
WALDO BROTHERS AND BOND CO., 181 Congress St., Boston.....	XI
WARREN FOUNDRY AND MACHINE CO., 11 Broadway, New York....	IX
WESTON & SAMPSON, 14 Beacon St., Boston.....	V
WHITMAN & HOWARD, 220 Devonshire St., Boston.....	V
WORCESTER, J. R., & Co., 79 Milk St., Boston.....	V

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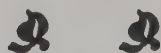
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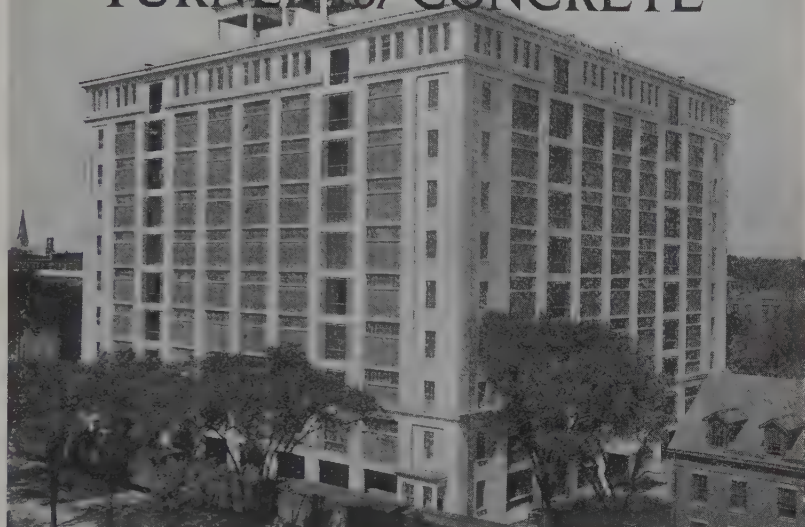
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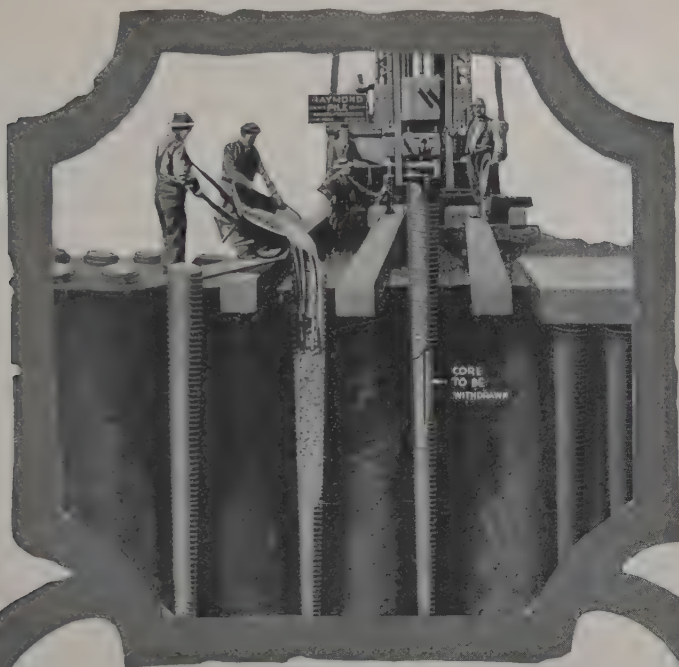
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